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Recommendations for the U.S. Coast Guard Survival Prediction Tool

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16. Abstract (MAXIMUM 200 WORDS)
The U. S. Coast Guard (USCG) Research and Development Center (R&DC) has developed new tools to estimate the survival of immersed and stranded (i.e., in survival craft) victims by search and rescue (SAR) planners. The tools include a thermal and dehydration model developed by the U. S. Army Research Institute for Environmental Medicine (USARIEM), an empirical model developed by the University of Portsmouth (UP), UK, and a maximum search time guideline. A panel of survival physiology subject matter experts (SMEs) was convened to provide critical reviews and discuss limits for use and set points for the models. The R&DC and its contractor Science Applications International Corporation (SAIC) also developed operational requirements for a software system containing these tools. The requirements are based on USCG SAR Program policies and feedback obtained from several Rescue Coordination Centers. The requirements and functionality were also presented to SAR planners for refinement and review.

This report documents the requirements and describes a proposed system that meets the requirements. It includes a "strawman" graphical user interface (GUI) presented to facilitate subsequent software design. The GUI depicts inputs, outputs, and victim status summaries that should be included, consistent with the requirements, along with other supporting information.

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EXECUTIVE SUMMARY

Background

The U.S. Coast Guard (USCG) is responsible for maritime search and rescue (SAR) operations within its area of responsibility. Not all cases are successful, and the SAR Mission Coordinator (SMC) must at some point consider whether to continue or suspend the search, "Active Search Suspended Pending Further Developments" (ACTSUS). This decision is a critical juncture for the victim, their families, and the USCG.

Predictions of the survivor's deteriorating physiological condition and future survival time are essential to the SAR planner during the search. The SMC uses these predictions to optimize the search resources, and for consideration along with other aspects of the search to make the ACTSUS decision.

Introduction

The USCG Research and Development Center (R&DC) was tasked by its sponsor, the Office of Search and Rescue (CG-534), with exploring and facilitating development of new approaches that would improve on the existing survival guidance tool. The R&DC worked with the U.S. Army Research Institute for Environmental Medicine (USARIEM), Natick, MA, the University of Portsmouth (UP), UK, the R&DC technical support contractor, Science Applications International Corporation (SAIC), and the R&DC support contractor MicroSystems Integration, Inc. (MSI), on this project. USARIEM developed and delivered a human physical model for the R&DC that simulates the heat and water balances of potential victims to estimate their survival times (STs). The UP developed a series of functional relationships based on multivariate regressions on data obtained from immersion cases documented in the UK National Immersion Incident Survey (UKNIIS). These two approaches to modeling victim survival were delivered to the R&DC during early 2008 and were subjected to independent review by a panel of experts in human survival physiology during the summer of 2008.

The sponsor further tasked the R&DC team with developing proposed requirements and functionality for a new survival guidance decision tool, and conditions for their use, based on technical peer reviews, stakeholder input from senior USCG operational SAR and CG-534 staff, and SAR program policies. This report documents the procedures and outcome of this process.

Approach

The Major Systems Acquisition Manual (MSAM), COMDTINST 5000.10, guided the operational requirements development process for determining the features and functionality of the survival guidance tool. The R&DC was tasked with developing requirements for a new survival tool that would be implemented either as a stand-alone application or as an embedded element of the USCG SAR operations environment.

The team reviewed current USCG operational policies involving ACTSUS and characterized operating practices by interviewing SAR controllers in several districts. We developed a preliminary set of requirements for review and refinement in a series of workshops involving subject matter experts (SMEs) and USCG operators. At this stage, some recommendations were set aside either because they were beyond the current tools' levels of sophistication, the data were difficult to obtain, or they would not increase the validity of the tool. The refined requirements, their origins, and the requirements that were set aside are provided in this report.

Outcome

The operational user interviews revealed that opinions of the current USCG victim guidance, the Cold Exposure Survival Model (CESM), varied by region. Command centers in colder climates relied on CESM guidance. Command centers in warmer areas found the model unusable because survival times predicted by CESM for ambient waters temperatures routinely exceeded the 36-hour maximum ST horizon in CESM, making the CESM guidance time irrelevant. Regardless of their location, however, command centers commonly apply multiple substantial safety margins to the CESM predictions. Beyond these margins, SAR planners may extend searches by additional significant periods beyond the times they consider appropriate in order to accommodate press attention or to comply with requests by public figures. Command center staff acknowledged that this extra search effort was made to show that they were making every possible effort to locate the victims. They reported, however, that the additional search time added to accommodate public interest did not significantly improve their success. They directly or indirectly indicated their lack of confidence in the ST predicted by CESM. They generally did not factor the CESM 'functional time' (FT) into search planning. Users also stated that they were often constrained by CESM's inability to process multiple victim scenarios. They also requested ST outputs in the form of a range of times versus a single "number in a box."

We concluded from the command center staff feedback that the current version of CESM does not adequately support their ACTSUS information needs. Their decisions frequently relied on considerations that were external to the search and to CG policy guidance. It is evident that the user community requires a significantly improved guidance tool, applicable over longer time periods, which lends more confidence to the extension of search times at higher ocean temperatures (i.e., above 24 ºC (75 ºF)). On the other hand, the operational users were clear in requiring that the role of the guidance tool should be to support and not dominate their final decisions in continuing or suspending the search. This and other responses from the operators, and program policies were used to draft preliminary requirements for the guidance.

We next held a workshop to obtain technical opinions of the proposed new models from survival physiology SMEs. Discussions at the workshop included theoretical, technical, and practical aspects of the models and their use. The technical workshop began with presentations on the USARIEM and UP model tools. The CESM developer also discussed features of the newest version of CESM, which includes the generation of a range of victim descriptions and STs from the information entered into the model. The project team presented a guideline for maximum immersion victim search time based on all available survivor information. Recommendations on the physiological decision points (set points) of expected incapacitation and/or death were presented to the SMEs by the project team. The discussion by the group centered on the effect of adopting the recommended body core temperature of 25 ºC (77 ºF) (currently 28 ºC (82 ºF) in CESM) associated with death due to hypothermia on increasing victim STs beyond reasonable values, particularly in warmer waters. The discussion was tabled for further examination by the R&DC.

Other significant SME discussion focused on the draft requirements for the model. The group discussed the probable availability of input information, focusing primarily on the availability of the victims' immersion scenario, clothing ensembles, and personal description. The group agreed that the tool must be able to generate output ST based on aggregate input information that include one or more ranges of survivor heights and weights, clothing, and immersion scenarios. An objective of the tool should be to allow for user input of a range of victim descriptions, rather than just a single victim, and display a corresponding range of outcomes.

The second workshop held at the annual Standardization Team Command Center Conference was attended primarily by command center watchstanders. This group's interest focused on how information would be entered and what summary information was desired. The group stated its need to simplify and minimize the volume of input information. At the same time, they needed to be able to visualize a range of outcomes in the scenario that resulted from ST changes associated with variations in the assumed clothing, environmental, or flotation conditions (raft vs. immersion). They also needed to have information presented in an easily interpreted format. The group presented its interpretation of the display and functionality needed to meet their requirements and solicited suggestions for features to add and remove that are reflected in Section 4 of this report.

A measure of success for the project emerged from the second workshop. The new guidance would be considered successful if operational users of the guidance tool ended their practice of adding multiple safety margins, primarily the additional 50 percent and 100 percent extensions of CESM ST predictions now in wide use.

This study proposes a stand-alone survival guidance tool application accessed through a graphical user interface (GUI) that combines the entry and display of inputs and outputs. Environmental inputs for the tool are either ingested from the Search and Rescue Optimal Planning System (SAROPS) environmental data server (EDS), or may be entered manually by the user. The GUI also permits the user to enter combinations of victim physical characteristics, clothing, and immersion states for scenarios involving individuals, small groups, or mass casualties. The models underlying the GUI calculate the probability of victim survival ($P_{Survival}$) as a function of time since the start of the incident, initial mortality (cold shock and swim failure), and hypothermia and/or dehydration, depending on ambient temperature. The GUI displays $P_{Survival}$ curves over time for the scenarios along with supporting information such as day/night periods, victim physiological deterioration level, time when $P_{Survival}$ reaches 50 and 10 percent, and prompts for next of kin notification and a point representing the maximum observed immersed [victim] survival time (MOIST) based on the existing survival data for immersion incident victims.

This report provides a high-level description of the tools recommended by the Survival of Mariners project for a new CG victim survival guidance tool. The 41 functional requirements developed for the tool are summarized in Section 3 and described in more detail in APPENDIX A. This report summarizes recommendations for a new USCG survival guidance tool that is accompanied by a recommended functionality for the tool's interface. We feel that an implementation of the guidance similar to that described in Section 4 of this report will provide a significantly improved picture of the condition of the victim and the search time window over the current CESM tool.

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LIST OF ACRONYMS

ACTSUS	Active Suspension [Active Search Suspended Pending Further Developments]
AIS	Automatic Identification System
AOI	Area of Interest
AVPU	Alert Verbal Pain Unresponsive
BMI	Body Mass Index
CC	Command Center
CDC	Centers for Disease Control and Prevention
CDO	Command Duty Officer
CESM	Cold Exposure Survival Model
CG	Coast Guard
CTM	Cold Thermoregulatory Model
DLL	Dynamic Link Library
EDS	Environmental Data Server
EPIRB	Emergency Position-Indicating Radio Beacon
FT	Functional Time
GUI	Graphical User Interface
HHS	Health and Human Services
HQ	Headquarters
IAMSAR	International Aeronautical and Maritime Search and Rescue
LOC	Level of Consciousness
MISLE	Marine Information for Safety and Law Enforcement
MOIST	Maximum Observed Immersed [victim] Search Time
MOS	Margin of Safety
MSAM	Major Systems Acquisition Manual
MST	Maximum Search Time
NIOSH	National Institute for Occupational Safety and Health
NOK	Next of Kin
NSS	National SAR Supplement
PDA	Personal Digital Assistant
PFD	Personal Flotation Device
PIW	Person in Water
POS	Probability of Success
PSDA	Probability of Survival Decision Aid
$P_{Survival}$	Probability of Survival
R&DC	Research & Development Center
SAIC	Science Applications International Corporation
SAR	Search and Rescue
SAROPS	Search and Rescue Optimal Planning System
SCTM	Six-cylinder Thermoregulatory Model
SMC	SAR Mission Coordinator
SME	Subject Matter Expert
SRU	Search and Rescue Unit
SST	Sea Surface Temperature

LIST OF ACRONYMS (CONTINUED)

ST	Survival Time
STAN	Standardization
UK	United Kingdom
UKNIIS	UK National Immersion Incident Survey
UP	University of Portsmouth (UK)
USARIEM	U.S. Army Research Institute of Environmental Medicine
USCG	United States Coast Guard

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1 INTRODUCTION

The Survival of Distressed Mariners Project led by the U. S. Coast Guard (USCG) Research & Development Center (R&DC) seeks to develop tools that provide victim survival time (ST) and probability of victim survival ($P_{Survival}$) estimates during search and rescue (SAR) cases. These cases involve victims who are either immersed (e.g., treading water) or afloat in emergency craft (e.g., life raft, surf board) on the ocean. The project goal is to provide better knowledge and guidance that will enable Coast Guard (CG) mission commanders and planners to improve the effectiveness and efficiency of SAR missions.

This project developed two new victim survival models. Each model calculates the duration and $P_{Survival}$ as a function of victim characteristics (e.g., height, weight, and clothing), and environmental variables (e.g., water temperature, air temperature, and wind speed). The U.S. Army Research Institute of Environmental Medicine (USARIEM), Natick, MA developed a computer-based biophysical model applicable to warm and cold environments. The model, known as the Probability of Survival Decision Aid (PSDA), predicts the victim's core temperature and dehydration state. The PSDA calculates victim temperatures in six regions of the victim's body by balancing heat generation through metabolism, heat transfer through blood flow, and heat loss through conduction, respiration, and sweating. The PSDA uses a mass balance approach combined with an empirical water loss calculation to estimate victim survival due to dehydration. The University of Portsmouth (UP), UK, developed an empirical victim survival model that is based on their analysis of the United Kingdom National Immersion Incident Survey (UKNIIS) database (Oakley and Pethybridge, 1997). The UKNIIS has accumulated information on victim exposure time, victim attributes (age, gender, build, clothing worn, personal flotation device use), local environmental conditions (water and air temperatures, wind speed, sea state, incident area), and incident outcome immersion incidents around the UK since 1992.

From the start of the project, it has been clear that the ability to develop and validate the models is hampered by a paucity of immersion incident exposure-survival data. The project initiated two tasks to address this problem in early FY2008. In a separate task, MicroSystems Integration, Inc. obtained an extract of the CG Marine Information for Safety and Law Enforcement (MISLE) system, a computer-based information system that captures data on marine safety, environmental protection/response, and law enforcement activities. The search of MISLE provided some exposure-survival data in a format equivalent to the UKNIIS in early 2008. The project team also searched recent and historical literature to obtain similar information. A medical subject matter expert (SME) on the project team also developed a summary review of fatal body core temperature and dehydration conditions. The review recommended that the fatal core temperature set point chosen for the new tool be lowered from 28 ºC (82 ºF) to 25 ºC (77 ºF) to reflect citations from medical and scientific literature.

In this final phase, the Survival of Distressed Mariners project determines how these new tools could be used to improve victim information available for the consideration of search suspension, "Active Search Suspended Pending Further Developments" (ACTSUS). This determination factors USCG policies, the current practices and needs of CG SAR watchstanders, and the technical merit and applicability of the new models that this project has developed.

2 DATA COLLECTION

Data collection covered the following topics:

- Review the role of victim survival in ACTSUS decisions as reflected in current CG SAR policies.
- Develop requirements for a new survival guidance tool based on CG policies and inputs from end users and CG SAR policy makers.
- Determine how the requirements could be met using available models and data based on inputs from survival physiology SMEs.
- Synthesize recommendations on how the CG should proceed in developing improved survival guidance for CG SAR operations.

2.1 Assembly of Policy and Practice Information

Guidance on the role of victim survivability in the decision to continue or suspend a search (ACTSUS) was compiled from a review of government-furnished excerpts of the International Aeronautical and Maritime Search and Rescue (IAMSAR) Manual, the Coast Guard Addendum to the United States National SAR Supplement (NSS) to the IAMSAR Manual (CG Addendum), and various USCG Area, District, and Sector SAR guidance documents.

The project team gathered information on the current role of victim survival information in the ACTSUS decision through interviews with command center personnel from both warm and cold water districts. Interviews were conducted in person or through telephone interviews. We sent a questionnaire to the commands prior to each visit that contained questions intended to get the responders' level of experience, their opinions on the functionality and performance of the Cold Exposure Survival Model (CESM), and the considerations and information involved in the suspension of a SAR search.

Project staff followed up the questionnaires with visits during May 2008 to gather information on current practices followed in developing ACTSUS decisions, and performance gaps with the following commands:

- Atlantic Area/District 5 Command Center (Portsmouth)
- District 1 Command Center (Boston)
- Sector San Juan (Puerto Rico)
- District 8 (New Orleans)
- District 9 (Cleveland)
- Pacific Area/District 11 (Alameda)
- SAR School (Yorktown)

Interviews began with a brief description of the project and its goals. The interviews then moved to a discussion of how each command center arrived at ACTSUS decisions, and the challenges they faced in arriving at the decisions. The application and interpretation of CESM, the role of CESM, and other factors were covered.

Command center representatives were asked to identify what necessary information was presently insufficient or missing. We asked the representatives for their opinions on how the features in a new guidance tool could be added or revised to improve survival information support to the ACTSUS decision-making process. We obtained their opinions on adding new functionality and inputs, and options for data presentation and ease of use. We asked questions concerning the benefits of historical and experimental data used in the development of the model. Policy and its influence on the use of survival guidance tools were discussed, and we asked if any policy modifications were necessary.

The information from the first set of interviews was used to generate a draft set of requirements. To generate the final set of requirements, we interviewed the following commands by telephone during August 2008:

- Atlantic Area/District 5 Command Center (Portsmouth)
- District 7 (Miami)
- Sector San Juan (Puerto Rico)
- District 8 (New Orleans)
- District 9 (Cleveland)
- Pacific Area/District 11 (Alameda)
- District 13 (Seattle)

2.2 SME Input

The project team held two workshops to obtain opinions and discussion from SMEs. The first was attended primarily by human survival physiology experts in the marine environment. This group provided their opinions on the suitability of the available models and data products for the CG survival guidance tool. The second group was composed of CG operational users familiar with operational requirements; they provided opinions on the operational requirements for the tool.

2.2.1 Technical Review Workshop

The technical review workshop was held in August 2008 to provide a forum for the discussion of the three victim survival models available for predicting the survival of immersed victims. The three models were presented by their principal developers: the PSDA developed by USARIEM, the CESM developed by the Canadian Department of Defence, and an empirical model based on the UKNIIS developed by the University of Portsmouth (UK). Section 3.2 devotes greater detail to each of these models. Invited SMEs from USARIEM, the University of Portsmouth, the Canadian Department of Defence, CG aviation medicine, and the USCG Headquarters (HQ) Office of Search and Rescue attended the meeting. The meeting focused on obtaining opinions and seeking a consensus on the suitability of each model for use in a new system. Discussions covered the applicability and capabilities of survivability models. We presented the draft requirements for discussion of their technical feasibility by the group. The group discussed the option of using an updated CESM , adopting a maximum ST guideline developed by the team, technical input on the operational requirements, feedback on the core temperature decision point (set point), and high-level discussion on defining the graphical user interface (GUI) input and output layers. The workshop minutes are in APPENDIX B.

2.2.2 Coast Guard User Workshop

The second workshop was held during the CG Standardization (STAN) Team Command Center Summit in Yorktown, VA, on September 19, 2008. The purpose of this workshop was to subject the survival tool requirements and draft functionality to SAR planning personnel. The workshop took advantage of broad participation by command center staff nationwide and included 13 USCG command center SAR watchstanders familiar with SAR mission planning that also had some level of understanding of CESM. The R&DC project team medical SME presented proposed operational requirements and functionality for the new survival guidance tool and then solicited responses during a discussion with the participants. The responses from this group form the basis for the final requirements and functionality of the system. The minutes from this workshop are in APPENDIX C.

3 FINDINGS

New information and models make it possible for the CG to improve the guidance on the condition of victims that it provides to SAR mission planners. The R&DC Survival of Distressed Mariners Project has developed the tools, requirements, and recommendations for functionality of a new survival guidance tool for SAR victims who are immersed or in survival craft in warm and cold environments. The requirements and functionality are based on CG SAR Program policies, end user needs, and technical tool capabilities. The tool can first be implemented as a stand-alone application that uses environmental and victim data as inputs. The program can calculate $P_{Survival}$ as a function of time based on initial victim mortality (due to cold shock and swim failure), and subsequent victim hypothermia and/or dehydration. The application would provide supporting information in the form of the Maximum Observed Immersed [victim] Survival Time (MOIST), day/night periods, and victim physiological deterioration level.

3.1 Coast Guard Policies and Practices

The procedures followed during SAR cases are unified throughout the CG by the CG Addendum and are modified to varying degrees by the districts and areas. In defining the functions of the guidance tool, the study examined how SAR policies and their interpretation in the Fleet influence its functional requirements.

3.1.1 CG Policies

The National SAR Plan designates the Coast Guard as the aeronautical and maritime SAR Coordinator for Search and Rescue Regions for which the U. S. is responsible outside of the continental U.S. and Alaska. The CG Addendum sets the requirements and goals for USCG SAR. The CG Addendum lists the following general objectives for the CG SAR Program:

- minimizing loss of life, injury, and property;
- minimizing risk to crew during missions;
- optimizing use of resources during mission; and
- maintaining a world leadership position in maritime SAR.

Performance measures are based on parameters including cases, responses, sorties, lives saved, lives lost (before and after USCG notification), lives unaccounted for, and assisted persons.

The USCG SAR Program has set benchmarks for the evaluation of SAR mission performance. Its FY2008 goal was to rescue 94 percent of persons in distress. This goal increases with successive years.

The CG Addendum states that cases may be suspended when it is apparent that further search efforts appear futile. The case is not closed, however, and can be resumed if new evidence arises indicating that either the victim was not in the area previously searched or that earlier information was incorrect. The CG Addendum leaves the decision to suspend with the SAR Mission Coordinator (SMC) and recommends a Suspension Checklist for their consideration while considering suspension. The checklist includes these major considerations for victim survival and accuracy of the search area:

- Was the search conducted in the correct place for the correct object?
- Was the location of the initial position certain?
- Is it possible that the victim survived the initial incident and after the incident?

3.1.2 ACTSUS Considerations in Coast Guard SAR Practice

The SMC considers victim survival, the search probability of success (POS) and many other factors in the ACTSUS decision. When victims are believed to be alive within the area of interest (AOI), the ACTSUS decision focuses on how well the AOI has been covered by the search, particularly if CESM is not providing useful guidance (e.g., ST > 36 hours). The discovery of evidence of the incident in the search area, such as the overturned boat, flotsam, or an oil slick, is considered as evidence that the AOI is correct. The POS based on completed and upcoming search sorties is evaluated subjectively. Factors such as the presence of coverage gaps in the AOI are considered. If personal flotation devices (PFDs) are believed to have been available to the victims but are not found in or near the debris field, the SMC may conclude that victims are afloat within the AOI and have not yet been detected.

The size of the AOI generally increases with the passage of time as the potential envelope of victim locations is dispersed by spatial variations in potential drift trajectories of the victims. The size of the search AOI and the capabilities of available search and rescue units (SRUs) factor into the POS for the next search sortie. A low POS resulting from a declining availability of search platforms and an expanding large search area may justify an ACTSUS decision. The threshold value for the next sortie's POS may be on the order of a few percent, and perhaps as low as less than 1 percent.

Other factors considered may include information gathered from the victim's next of kin (NOK), such as the victim's will to live, level of physical fitness, water skills, and age. Interviews of friends may provide information about the intended trip, equipment carried on the vessel, and the victim's capabilities and level of knowledge. Non-survival considerations for search suspension fall mainly under the judgment of the SMC or District Commander and are in line with the overall SAR ethos for suspension: "What if it was my child?" Consideration is also given to the safety of USCG personnel during rescue; for example, when crews become exhausted or weather conditions pose a hazard to USCG personnel. The SMC is therefore considering a range of factors when ACTSUS is considered.

The CG Addendum requires SMCs to use CESM to provide ST guidance in cases involving persons in the water (PIWs). The perceived value of CESM tended to vary with the climate of the district or area. We found that command centers in colder climates relied on CESM, whereas those in warmer areas found the model unusable because the maximum ST horizon in CESM only extends to 36 hours. SMCs in warmer districts and areas tend to rely on non-survival factors because the CESM ST prediction would always or nearly always be greater than 36 hours. These SMCs tended to follow customs followed by local authorities (i.e., fire and police) to dictate the timing of the USCG suspension. A typical practice cited for a warm-water command center is to search for three days, significantly longer than the 36-hour CESM window.

Regardless of the location, command centers apply multiple and substantial safety margins to the CESM predictions. Command center staff responded that they would extend the search out to 150 percent to 200 percent of the CESM-predicted ST. They also indicated that they did not use the CESM 'functional time' in planning searches. A second safety margin added was the so-called "natural suspension time" at sunset. Customary CG practice is to add an additional daylight period or to search until the next time of dusk before contemplating ACTSUS. They either directly or indirectly indicated that they lacked confidence in the accuracy of the 'CESM time,' the ST predicted by CESM.

Media attention and pressure from politicians or prominent public figures weigh prominently on the decision to extend the search. Suspension generally did not occur until media attention had subsided; when the victim's family was able to generate attention by a prominent political figure, the search would be lengthened an additional day. Command center staff acknowledged that the extra search effort was done to show that they were making every possible effort to locate the victims. They acknowledged, however, that these additional searches in response to outside influences were not successful. External attention is therefore a significant driver of the quantity of search that does not affect its success. Public attention can be a major issue in all districts, but its significance appears to be more prevalent in warm-water districts where the victim may survive several days.

This feedback convincingly showed that across the CG SAR community, SMCs lack confidence in the accuracy of the CESM ST prediction, so their decisions shift to other criteria. The user community needs significantly improved victim survival guidance that is applicable over longer time periods, lends more confidence to the extension of search times at higher ocean temperatures (i.e., above 24 ºC (75 F)), and can accommodate a wider range of victim scenarios. On the other hand, the operational users were clear in requiring that the role of the guidance tool should be to support and not dominate their final decisions in continuing or suspending the search.

3.2 Victim Survival Models

This section provides a high-level description of the discussed models. More detailed descriptions can be found in the references.

3.2.1 Probability of Survival Decision Aid (PSDA)

The PSDA is a six-cylinder thermoregulatory model (SCTM) for heat exposure and prolonged cold exposure in the air or water based on USARIEM's existing Cold Thermoregulatory Model (CTM) (Xu, et. al., 2008). PSDA provides survival estimates for hypothermia and/or dehydration situations using mechanistic hypothermia and dehydration models, and a supplemental empirical water loss model (Xu, et. al., 2008). PSDA divides the body into six cylinders: head, torso, upper leg, lower leg, upper arm, and lower arm. Each cylinder is further subdivided into concentric layers consisting of the core, muscle, fat, and skin, with an optional outer clothing layer. The blood pool is treated as a separate compartment. Body morphology is used to estimate the size of each layer or compartment.

PSDA takes into account physiological mechanisms that include metabolic heat production, shivering metabolism that includes the gradual loss of shivering metabolism at low core temperatures, sweating heat loss, respiratory heat loss, and blood circulation. It predicts both core and skin temperatures in each physical element.

PSDA provides two mechanisms for estimating dehydration. The first approach is a mechanistic water balance equation that accounts for water losses from the kidneys, evaporation from the lungs, and through sweating. The second approach is empirical, based on realistic field experiments conducted shortly after World War II (Brown, et al, 1947). The PSDA developer has noted that the skill of the model in estimating the survival of immersed and semi-immersed victims is approximate because no experimental data exists to document sweating rates of immersed subjects.

PSDA is a modular software program that can be accessed as a callable subroutine from a dynamic link library (DLL). It is presently integrated with a GUI for testing during this project.

Inputs include the following parameters:

- Air temperature
- Water temperature
- Relative humidity
- Wind speed
- Victim description: gender, height, weight, body fat percentage
- Victim clothing

Outputs include cold functional time (FT), cold ST, and dehydration time for both PIW and survivors in emergency craft. Current set points are 34 ºC (93 ºF) for cold FT, 30 ºC (86 ºF) for cold ST, and loss of 20 percent of body weight for dehydration time. USARIEM has set 120 hour and 240 hour maximum survival time caps for immersed and dehydrated victims, respectively. The 120 time is based on the maximum observed immersion survival time with a 33% margin of safety). The 240 hour limit was set to coincide with the survival curve created by Brown, et al (1947). These set points may be reset at the discretion of the CG.

3.2.2 University of Portsmouth (UP) SAR Victim Empirical Survival Model

The SAR Victim Empirical Survival Model was developed by the University of Portsmouth, UK. The model uses a reliability theory of aging and longevity to create equations that estimate survival probabilities as functions of time, and victim and environmental variables. These relationships are based on the UKNIIS, which documents the outcomes of 1593 accidental immersion cases in the UK between the years 1992 - 2006. The equations use the Weibull distribution as their basis function (McCormack, et. al., 2008). The UKNIIS contains 20 independent variables. McCormack found that five of these variables were significantly correlated with ST:

- Water temperature
- Water area (coastal, offshore, etc.)
- Age of victim
- Clothing
- Use of PFD

The UP SAR Victim Empirical Survival Model consists of a family of equations that predict $P_{Survival}$ of a victim or group of victims as a function of combinations of the variables and time.

3.2.3 Cold Exposure Survival Model (CESM)

CESM is a stand-alone commercial software program used to predict core temperatures for victims in water and air. CESM version 2.2 was developed by Defence Research and Development Canada. CESM version 2.2 is currently in use by USCG command centers to provide estimates for maritime SAR victims.

The users access CESM through a GUI that provides for inputs and outputs on a single screen. CESM accepts the following inputs:

- Victim description: height, weight, age, body fat percentage
- Victim clothing
- Victim fatigue level
- Degree of immersion (ranging from air-only to all-but-head)
- Wind speed
- Air temperature
- Relative humidity
- Water temperature
- Sea state

The CESM model outputs FT (i.e., time to loss of cognitive function) and ST. In addition, CESM version 2.2 draws on statistics from the UKNIIS to output the probability of the victim surviving stressors unrelated to hypothermia such as traumatic injury or drowning.

3.2.4 The Maximum Observed Immersed [Victim] Search Time (MOIST) Guideline

As part of its supplemental tasking for the R&DC, the UP combined immersed victim data from the UKNIIS with similar data assembled by SAIC during its literature search and data synthesized by MicroSystems Integration, Inc. from the USCG Marine Information for the Safety and Law Enforcement (MISLE) database. The MISLE immersed victim data were extracted from only the southern CG districts, and both CG AREA commands. This data supplemented the UK data, which consisted almost entirely of cold water cases with warmer water data to explore whether a more representative data set would improve the predictive ability of the UP SAR Victim Empirical Survival Model, particularly in warm water. The combined data base contained 2254 data points; however, the data obtained from the USCG MISLE database and the SAIC literature search generally provided only victim immersion time, water temperature, and victim outcome information. After examining this combined data base, the UP determined that the empirical model relationships should be restricted to the original UKNIIS and its boundaries: for water temperatures less than 14 ºC (57.2 ºF) and periods less than 14 hours.

The R&DC also examined this information to see whether other useful relationships could be extracted from the combined data set. The exercise focused on how the data could empirically support the ACTSUS decision. In these cases, the R&DC assumed that the victim would not have succumbed to the short-term mortality processes of cold shock or swim failure and would have lived for at least an hour. The R&DC also removed cases that had been included in the data base for the USS Indianapolis case during World War

II (317 survivors out of 321 victims with typical exposures of four days at 29.4 ºC (85 ºF)) because the data was poorly documented. This left 501 survival cases.

The R&DC examined the remaining cases and selected a subset of survival cases that characterized maximum survival durations across the range of observed sea temperatures. Thirteen cases were selected that spanned the range of temperatures between 2 ºC to 27.8 ºC (35.6 ºF to 82 ºF) (Figure 1). The corresponding STs range from 5.3 hrs to 93.6 hrs. These thirteen of the 501 survival cases represent the extremes of observed human endurance. The trend of these cases is approximately log-linear, with two exceptions. The longest duration point (148.5 hrs, 20 ºC/68 ºF) represents a case where two boys were blown off the coast of South Carolina and recovered six days later near Cape Hatteras. Because this case did not represent immersion, it was removed from consideration. The other ‘outlier’ represents the case of Rob Hewitt, a New Zealand diver who survived 75 hours in 16 ºC (61 ºF) water. Hewitt’s case represents the best possible combination of factors for survival: a trained diver who took advantage of every opportunity, positive mental attitude, and full wet suit with hood and gloves.

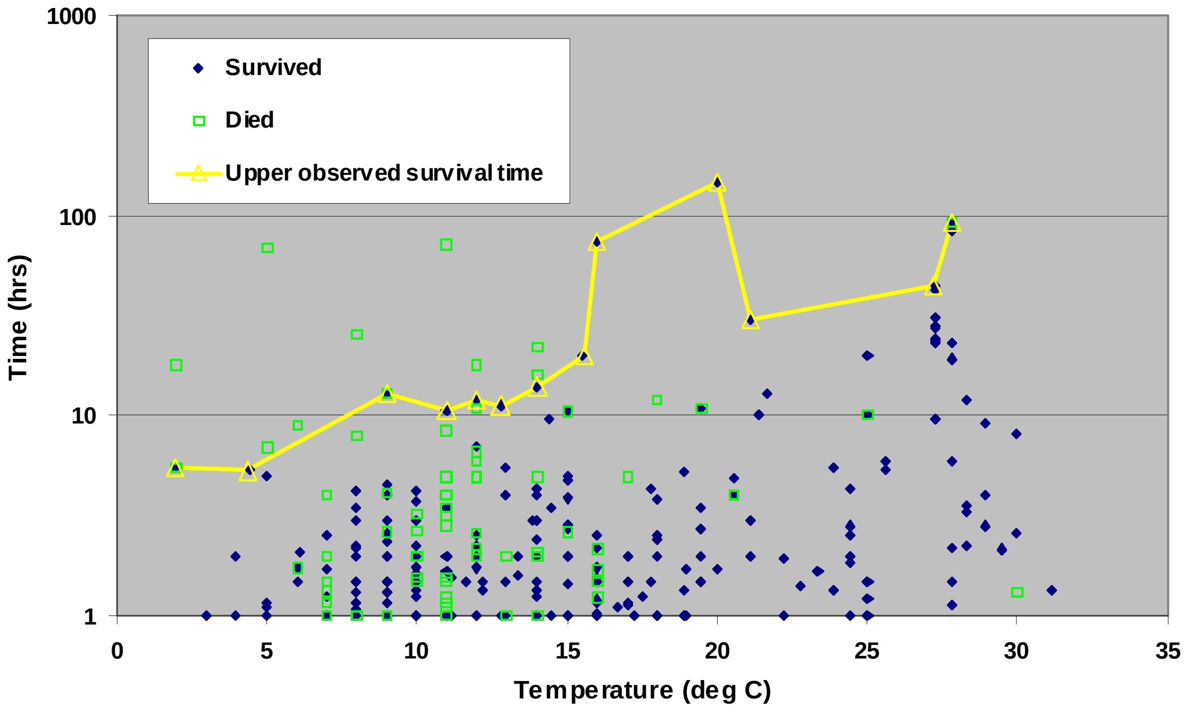

Figure 1. Thirteen extreme survival cases selected by the R&DC for analysis.

In each case, however, the victim would have survived some indeterminate period longer, so a safety margin based on the upper 95th percent confidence interval was added to account for potential additional ST in extreme cases. The influence of the variance around the regression, particularly the contribution added by the Hewitt case, is to increase the safety margin for victims. The net effect is that the upper confidence interval spans all but one (Hewitt) known immersed victim survival case.

We have generated the Maximum Observed Immersed [victim] Search Time (MOIST) relationship from the log-linear trend of the twelve extreme survival cases as a function of water temperature, plus a margin of safety. The margin of safety accounts for the variability of observed live victim recoveries around the guideline for immersion victims. The functional expression for MOIST in hours is

MOIST = 5.75 * exp(0.1* SST),

where SST is the sea surface temperature (ºC) and exp is the exponential function. The relationship of MOIST to observed survival cases is shown in Figure 2.

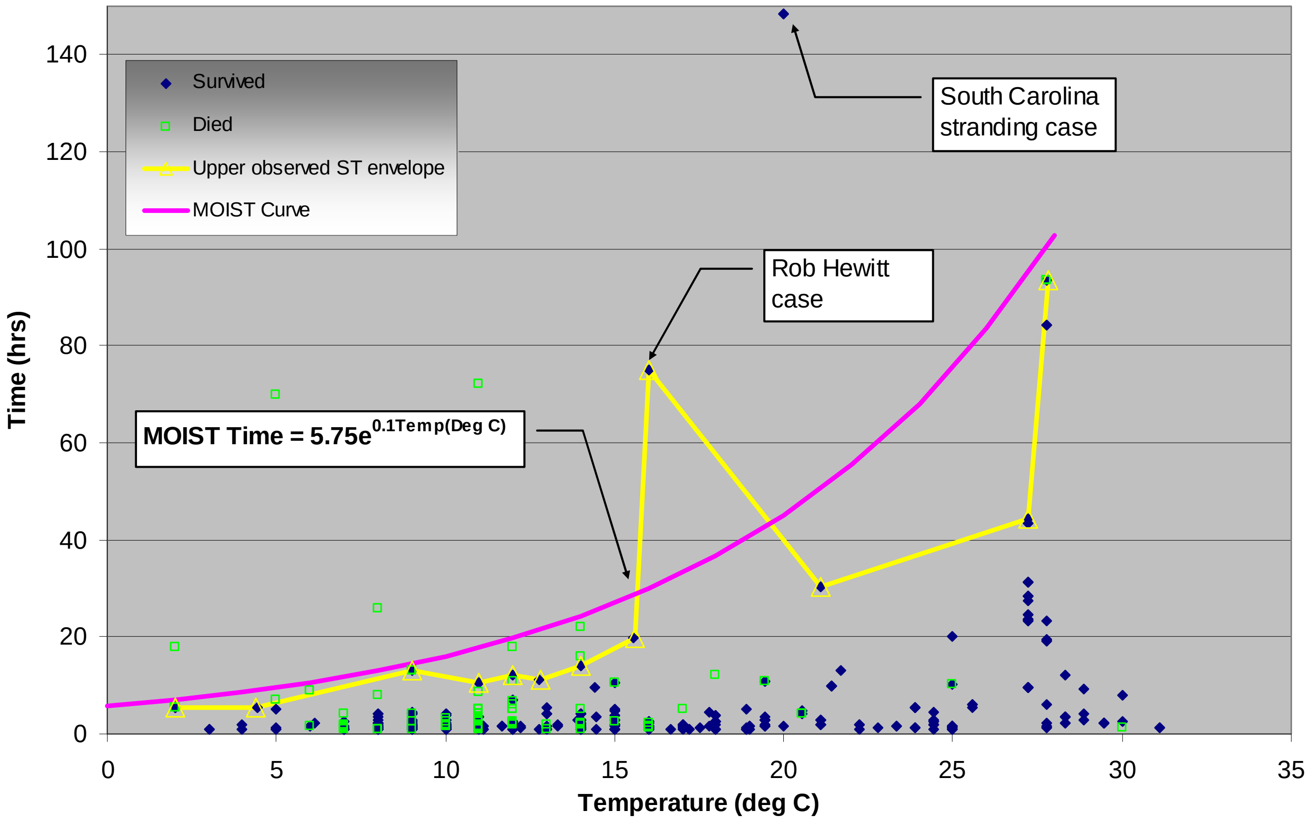

Figure 2. MOIST guideline function and the final twelve extreme survival cases.

MOIST represents the maximum time that a living immersed victim could be found at the ambient water temperature, based on available information. MOIST applies to all victim descriptions and all clothing ensembles (e.g. survival suits), but is limited to immersed victims, as opposed to victims in rafts or partially immersed. As described above, it is based on a small subset of extreme survival times across a wide range of water temperatures. The MOIST curve is the log-linear fit to the data with an upper 95th percentile confidence interval added. MOIST therefore factors in both the trend and the variability of the observed data. The curve may be of most practical value at water temperatures above 15º C (59 ºF), where immersed victim survival times approach or exceed the 120 hour limit set in PSDA. The MOIST relationship is intended to (1) provide a means to incorporate our knowledge of extreme survival possibilities, and (2) convey to the SMC that in the absence of other information (e.g. that the victim may be aboard a raft or have gone ashore), case information does not support the assumption that the victim may still be alive.

3.2.5 Model Comparisons

Table 1 summarizes the guidance tools on the basis of their processes, input parameters, and limitations.

Table 1. Side-by-side comparison of model characteristics and functionality.

Name	Developing Agency	Mathematical Basis	Human Body Representation	Environmental Parameters			Flotation	Set Points			Inputs	GUI	MST (hours)
				Cold	Warm	Dehydration		FT (°C)	ST (°C)	Dehydration			
Probability of Survival Decision Aid (PSDA)	US Army Research Institute of Environmental Medicine (USARIEM), Natick, MA	Energy balance equation (metabolic heat production, shivering, heat conduction, blood convection)	6 cylinders (head, thorax, arms, legs)	Yes	Yes	Yes	Assumed	34	30	20%	Clothing, height/weight, %fat, immersion level (neck, thorax, waist), temperature (air, water), humidity, wind speed	Yes	120
Cold Exposure Survival Model 2.2 (CESM 2.2)	Defence Research and Development Canada – Toronto	Heat transfer between body and environment based on known physiological and biophysical principles (calibrated with known survival cases)	1 cylinder	Yes	No	No	Assumed	34	28	N/A	Gender, age, height/weight, body fat, fatigue, immersion level, temperature (air, water), humidity, wind speed, sea state, garments	Yes	36
UP SAR Victim Empirical Survival Model	University of Portsmouth (UP), UK	Regression analysis of the UKNIIS (1593 incidents)	N/A	Yes	No	No	Input	N/A	N/A	No	Exposure time, age, gender, body build, clothing, PFD, temperature (air, water) wind speed, sea state, incident outcome	No	14 (limit of data)
Maximum survival time guideline	USCG	Regression analysis of a subset of 12 (out of 501) long term survival cases	N/A	Yes	Yes	No	Assumed	N/A	N/A	No	Water temperature	No	N/A

3.3 Model Set Points

The project team had earlier developed recommendations for victim core temperature and victim body weight loss due to dehydration at death set points based on the medical literature. The review concluded that "reports of lethal core temperatures vary dramatically, ranging from 15.7 ºC (60.3 ºF) to 32 ºC (89.6 ºF), with the lowest recorded temperature from which a victim recovered was 13.7 ºC (56.7 ºF). The extremes are very few in number and therefore not significant." The report concluded "assuming flotation is available, death due to cardiac arrest and respiratory failure is highly likely to occur at a core temperature of 25 ºC (77 ºF) and is ensured at a core temperature of 21 ºC (69.8 ºF). Without flotation, death due to drowning from incapacitation is likely to result at a core temperature of 27 ºC (80.6 ºF) (SAIC, 2008). Very little information was available to support the choice of a fatal dehydration condition. The review found that "death from dehydration results when water loss is in the range of 15 - 20 percent of body weight" (SAIC, 2008).

The core temperature set point information was presented and discussed with the physiology SMEs at the first workshop. The group concluded that because the extreme survival cases that supported a recommendation of 21 ºC (69.8°F) were not of a marine nature, they would not be applicable to immersion survival. The SME group then considered adopting the 25°C (77°F) and 28°C (82.4°F) set points. The project team advocated adoption of the 25°C (77°F) core temperature set point because it is the lowest survivable temperature where spontaneous ventricular fibrillation and cardio respiratory failure occur. The workshop group could not reach a consensus on the practicality of 25°C (77°F) in the tool because even a very low basal metabolism can maintain victim core temperatures above 25 ºC (77°F) in water temperatures above 23°C-25°C (73.4°F - 77°F).

The project team subsequently conducted a modeling exercise to resolve the influence of 25 ºC (77°F) versus 28 ºC (82.4°F) set point. The PSDA model was exercised to evaluate the influence of varying the core temperature at death on ST. Two clothing scenarios were examined: nude and heavy marine suit for males and females of medium height and build. The exercise found that both groups of subjects would come into thermal equilibrium at water temperatures between 15 ºC-20 ºC (59°F-68°F) (depending on the insulation and gender of the individual). Differences in ST produced by varying the set point ranged from 3.5 to more than 14 hours. ST differences within a gender/clothing scenario were larger for females and for subjects wearing heavier clothing. The project team's finding is that the information supporting a core-temperature-at-death set point decision is not conclusive. The ability of any thermal model to accurately predict victim survival at temperatures above 15 ºC-20 ºC (59°F-68°F) remains impaired by the paucity of human core temperature and survival data. The 25 ºC (77°F) set point increases the implicit margin of safety of the guidance through the adoption of conservative assumptions, particularly in cold water scenarios.

The literature review effort found only limited information to support a dehydration condition. The dehydration set point recommended by the team of 20 percent loss of body weight was accepted by the SME group.

3.4 Guidance Tool Input Functionality

SAR watchstanders responded that they may either have very detailed or very limited victim information at the start of a case. Their response translates to the requirements for simple victim entry functions that can support pre-set scenarios for cases when little information is available for the victim (i.e., only gender), as well as detailed information as it becomes available. Operators are also required by SMCs to provide summaries for multiple scenarios in which varied clothing or immersion situations must be developed to describe best- and worst-case scenarios. The physiology SMEs also recommended the provision of a recalculate function that would allow users to backtrack through the data entry process to generate updated survival summaries with new information.

The Search and Rescue Optimal Planning System (SAROPS) environmental data server (EDS) is capable of providing environmental inputs to the guidance tool. Operators presently rely on point observations from offshore buoys for this input. Data from these buoys may not be representative of local conditions. Operational model products similar to those presently used by SAROPS for wind and surface current inputs would likely provide more representative local information. SAR watchstanders also requested the option of manual data entry for local conditions.

3.5 Output Presentation Layer

Users responded that victim summaries based on graphical tools were preferable to the simple single numbers for FT and ST currently provided by CESM. Our proposal to add a guideline for the MOIST time based on ambient water temperature was favorably received by the physiology SMEs. They also agreed that the inclusion of a summary of historical survival cases under similar conditions would be beneficial to SMCs.

The opinions of operational users attending the second workshop were generally similar, with some notable exceptions. They did not want to have historical data displayed in the GUI, because that information can be released to others (e.g., to NOK who might be briefed on the case) and subsequently misinterpreted. The operational users asked for a summary of the present physiological condition of the victim (as a function of temperature) in order to improve their understanding of the present mental and physical status of the victim (such as unconsciousness, delirium, cardiac failure). This information would allow them to gauge the victim’s survival prospects. A window of functionality depicted on the graph was requested by the operators to give a visual cue to the key period of time for recovering a survivor. The operational users also accepted the MOIST guideline for search suspension to define the upper time limit for survival.

The operational users wanted the GUI displays simplified so that members of the public, such as NOK, would have a clearer understanding of the situation and fewer reservations about the ACTSUS decision. They supported adoption of the GUI graphical output format showing trends in $P_{Survival}$ during the search time window. The sponsor stated that $P_{Survival}$ on the y-axis of the graph must use a non-numeric scale instead of the percent scale initially proposed. We are proposing the gradient of Good, Fair, Poor, and Unlikely/Deceased as the replacement. Operational users want the ability to display multiple curves representing best-, worst-, and index-case scenarios (viewed as three or more separate curves on the graph). Users finally want the ability to easily export the guidance output summary to MISLE, SAROPS, or other report format (such as Microsoft® Office Word® or .pdf).

Training in use of the model is another area that was recognized by users as requiring additional consideration. The project team learned that CESM training is frequently truncated, preventing greater understanding of the model and its value. It would be beneficial to end users and controllers to devote greater training time to integration and use of the model in developing and implementing the SAR plan. This education will greatly increase the knowledge of the overall value and limitations of the tool, as well as foster trust in its output.

3.6 Survival Guidance Tool Requirements

The functional requirements are listed in Table 2. Forty-one requirements remained after the vetting process; another eight items were rejected or identified as possible candidates for future work. The project team assigned numbers to track the requirements according to their source and disposition. The ID numbers do not represent a relative priority of the requirement. All requirements considered are presented in Appendix A along with their source and disposition.

Table 2. Survival guidance tool functional requirements.

ID	Description
1	Predict survivability of a PIW immersed with head above water
2	Provide solid supporting information but not dominate, or increase the difficulty of, the decision to continue or suspend a search
3	Incorporate survivor, experimental, and modeled data to increase user confidence and range of applicability including the ability to base decisions regarding asset allocation on results of the model
4	Update parameters to accommodate changes in terminology
5	Use core temperature of 25 ºC (77 ºF) as the victim's survival limit for cold exposure resulting in hypothermia
6	Use 20 percent loss of body weight to define the victim's survival limit for dehydration cases that do not involve immersion to the neck
7	Apply tool to maritime SAR cases involving victims in the water and victims in survival craft (excepting witnessed submersions)
8	Define victim survival based on victim core hypothermia
9	Define victim survival based on victim percent dehydration
10	Provide ST guidance based on analyses developed from historical event data to describe expected victim ST
11	Employ GUI that makes use of pull-down menus, automatic data download, radio buttons, and pick lists to expedite operator input
12	Validate algorithms and outputs against a data base developed from mathematical equations and include in an application describing heat transfer from the human body to an environment (water or air), ultimately determining the time of heat transfer to a critical core body temperature; the application will have been reviewed in scientific literature journals
13	Provide ACTSUS decision makers with an explanation of scientific rationale and processes behind the tool's functionality so they will better understand the limitations of the model
14	Provide a "deterministic" model with the option of selecting a $P_{Survival}$ output capability as a probability distribution; include a stochastic excursion (stochastic processes are non-deterministic, in that the ultimate outcome cannot be guaranteed by educated hypothesis)
15	Assume that the victim can maintain an open airway
16	Assume flotation assistance and/or PFDs are available to and used by the victim
17	Account for the physiological effects of body core hypothermia on the victim
18	Incorporate air and water temperature information, encompassing the range of values encountered in Coast Guard areas of responsibility
19	Provide a means to quantify the condition of the sea surface (e.g., calm or rough sea state) based on environmental data products (e.g., operational environmental models or real-time data from remote surface buoys) that will allow the calculation of victim heat transfer coefficients based on sea surface turbulence
20	Make the tool automatically ingest environmental data in electronic format (e.g., EDS) or allow for manual input of environmental data: water temperature, air temperature, and sea state

Table 2. Survival guidance tool functional requirements (Continued).

ID	Description
21	Automatically convert inputs/outputs in degrees Celsius to Fahrenheit and vice versa
22	Incorporate information on victim clothing
23	Incorporate information on victim gender and morphology
24	Allow the user to enter case data (date, time, MISLE number), environmental data, and victim characteristics in a single window
25	Allow the user to develop and apply pre-set scenarios for a case (including a default victim for cases where specific information and parameters are unknown)
26	Account for the time the victim has spent in the water
27	Account for and calculate the physiological effects of dehydration on the victim
28	Account for depth of immersion (to the neck) and/or degree of wetness in terms of percent of body directly exposed to the ocean surface
29	Process case input parameters using deterministic and statistical models, as appropriate for conditions, to derive victim survival information
30	Allow the deterministic model to define both the "victim" solution based on the best estimate of the inputs, and a "$P_{Survival}$" solution based on random variations of victim input parameters (e.g., variations of height, weight, and clothing)
31	Incorporate a recalculate function to allow the user to change one or more input parameters and re-run the case
32	Allow for several scenarios to be run on various victim parameters if detailed victim data is not known or is unavailable
33	Provide output in GUI form showing victim core temperature and dehydration data from the deterministic model over a time continuum
34	Include predicted ST in the output based on the range of expected STs derived from variations in victim characteristics, and the MST based on historical data
35	Include a graphical summary of victim $P_{Survival}$ as a function of time based on the randomly varied victim inputs
36	Allow users to run multiple scenarios and display their output simultaneously
37	Process a time window of up to 120 hours (90 hrs + 33% margin of safety (MOS))
38	Display the input parameters in the output window
39	Provide a summary report containing all input parameters and output data from each run
40	Produce the final report in a format that can be ingested into the MISLE data base
41	Include a hyperlink function which leads users to a simplified version of the graphic output for NOK presentation

3.7 Impediments to Improving Survival Knowledge

This section discusses the knowledge gaps that currently pose the most significant impediments to our understanding of survival factors.

3.7.1 Physiological Factors

The USARIEM PSDA model is the central predictive component of the system recommended by the R&DC Survival of Distressed Mariners Project. PSDA calculates victim survival based on physiological processes that are relatively well understood; however, other physiological factors also affect survival. These factors include heart failure related to the initial shock of cold immersion, loss of physical or cognitive functionality due to hypothermia, and exhaustion in warm and cold environments. These limitations complicate model development and ultimately mean that the model should be used with caution.

<u>Gap 1:</u> The influences of other physiological factors on victim survival are not sufficiently understood to merit their incorporation into a predictive model.

3.7.2 Available Physiological Data

The validation of PSDA was limited by the available physiological data. The model-data comparisons fell into the following categories:

1. A comparison of predicted and measured subject core temperatures in controlled experiments to validate the shivering and metabolism sub-model.
2. Accidental immersion cases where victims survived. The model-predicted ST was compared to the observed exposure.
3. Accidental immersion cases where victims died. The model-predicted ST was compared to the endurance of the victims at death.
4. Controlled experiments using English Channel swimmers. Model-predicted and observed core temperatures on completion of the swims were compared.
5. One long-term air exposure case for a woman trapped in an overturned car for 7 - 8 days.
6. Model-predicted STs for an average male across a range of temperatures were compared to STs from historical studies.

Each type of comparison provides limited support to the validation of PSDA. In example 1, the range of core temperatures was limited by the need to protect the subjects' safety. For example 2, we have no information of the victims' core temperatures upon their recovery for comparison to model predictions, and we do not know how much longer they would have survived. In example 3, we do not know whether the victims' actual core temperatures dropped below the critical values, consistent with the model-predicted values. The subjects in example 4 may not be considered as representative of the rest of the population. They had undergone athletic training to acclimate themselves to cold exposure, they were swimming, so their heat loss rates differed from those experienced by normal immersion victims, and the range of core temperatures they experienced did not approach critical values. For examples 5 and 6, we lack information on the actual victims' height, weight, and clothing, we do not have information on their condition upon recovery, and we do not know how much longer they would have survived.

The purpose of the discussion above is to point out that our ability to confidently field a model is constrained by the availability of human subject data. We believe that USARIEM took advantage of every significant data set available in validating the PSDA model. The model represents the best available science for a mechanistic immersion victim survival tool, and should be implemented. The final recommendations by USARIEM, however, include the following precaution (Xu, et. al., 2008):

> *Due to lack of sufficient data for validation, the PSDA model should be considered, to a degree, untested and, thus, used with caution. PSDA is a tool that allows the USCG user to analyze possible survival scenarios and to better assess the situation. PSDA can be used to assist the USCG search and rescue personnel in making decisions, but cannot be used as the primary basis for making search and rescue operation decisions. Any decision to suspend a search and rescue mission should be made by USCG search and rescue personnel.*

The uncertainty of victim core temperature at death was raised early in the project. We attempted to answer this question through a comprehensive review of the literature on fatal core temperatures, which produced a relatively small number of cases that indicated death could occur over a range of core temperatures. We have recommended the adoption of a protective value of 25 ºC (77 ºF) for this set point. The survival physiology SMEs at the first workshop, however, felt that the value selected was too conservative, because victims in a marine environment must be able to maintain an open and cleared airway in addition to a sufficiently elevated core temperature. As victims become increasingly incapacitated, they cannot adequately respond to these demands from the marine environment. In summary, we have selected a core temperature of 25 ºC (77 ºF) as representative of the fatal condition. Other opinions expressed by the physiologists were that values of 28 ºC (82 ºF) and 30 ºC (86 ºF) are more appropriate.

Gap 2: Scientific understanding of victim thermal conditions at the point of death and the variability of these conditions are inadequately supported by available information.

3.7.3 Dehydration Factors

No long-term raft survival data were available to USARIEM during the validation of the dehydration component of their model. They felt that their predictions of long-term victim survival are poorly supported by documented cases. For this reason, PSDA sets time limits for the duration of the simulations: 120 hours for immersion, and 240 hours for air exposure.

USARIEM also found no experimental data on water loss due to sweating by immersed victims.

Gap 3: The existing data on the fatal dehydration (20 percent body weight loss) of victims exposed for long periods of time when immersed or in emergency craft do not adequately support decision-making.

3.7.4 CESM Training

In our opinion, CG SAR watchstanders do not adequately understand the fundamentals behind the CESM model currently used for victim survival. Participants in the CG User Workshop indicated that they viewed CESM as a "black box" into which they "punched the numbers." They also stated that they had received either cursory or no training on the theory and operation of CESM during SAR School training.

Gap 4: CG SAR watchstanders lack adequate appreciation and understanding of the physiology of victim survival in the marine environment and training in the components of the current SAR planning tool.

3.7.5 Survival Times

During the course of this project, we had the opportunity to meet with English and French SAR planners. We were also contacted by SAR controllers from the U.S. Air Force in Korea and the New Zealand Defence Force. From these discussions, we learned that SAR planners are globally faced with the same uncertainty about victim ST in their cases. The British and French reported that their responses to media and political figure attention and involvement are to similarly lengthen searches until interest subsides. They were therefore very interested in seeing and contributing to the development of an improved tool.

During this project, we also learned of related work by Dr. Jennifer Lincoln, a researcher for the National Institute for Occupational Safety and Health (NIOSH), part of the Centers for Disease Control and Prevention (CDC) within the Department of Health and Human Services (HHS). NIOSH is the federal agency responsible for conducting research and making recommendations to identify and prevent work-related illness and injury. Dr. Lincoln works in NIOSH's Alaska Field Station, where she leads the "Applying Safety Research and Design to the Fishing Industry" research program. Her work focuses on efforts to improve the safety of commercial fishing vessels in Alaska and how improvements implemented there could benefit other fishing regions of the United States.

Dr. Lincoln conducts field investigations of fishing vessel incidents in Alaskan waters. During the course of our study, we found that she was interviewing victims following major incidents, including the *Alaska Ranger* and *F/V Katmai* incidents. Dr. Lincoln's presence on the scene of incidents, interest in medical and physiological outcomes, and focus in victim safety are very close to CG-534's interests, and she has indicated her willingness to collaborate with us. For example, Dr. Lincoln interviewed surviving crew members during the *Alaska Ranger* incident and could have obtained information on the heights, weights, clothing, and survival suit performance of the crew. We also determined that the symptoms and core temperatures of one deceased and 20 surviving crew members rescued by the *CGC Munro* were measured and recorded during the triage process. In the long term, victim data of this nature will significantly improve our ability to quantify the human outcomes of SAR cases.

<u>Gap 5:</u> Opportunities for improved collaborative data collection and sharing between international agencies and other federal agencies exist and should be exploited to improve the SAR community's knowledge of victim survival.

4 RECOMMENDATIONS

This report has described the new products developed by this project, reported on the technical merit of each product, and described the information required to support CG operational needs. This section contains our recommendations for next steps in the process. We begin with a description of the functionality of the new survival guidance tool. Sections 4.1 and 4.2 are intended to provide sufficient information to support development of specifications for software development.

The lack of information on the human element SAR cases, primarily of the physiological impacts of exposure and the outcomes of SAR cases represented the principal obstacle to our ability to improve the CG's survival guidance tool. The knowledge gaps are discussed in Section 4.3, and include a related information gap pertaining to watchstander understanding of the existing CESM guidance. Section 4.4 provides recommendations for actions to address the information gaps.

4.1 General Recommendations

The project has developed sufficient information to support the development of a new stand-alone software tool for immersed and stranded victim survival prediction.

The tool should initially be deployed as a stand-alone application that resides on each SAROPS server.

The USARIEM PSDA should be the central element of the software tool. We recommend adoption of the 25 C (77 ºF) core temperature set point; however, this point should be revisited. The dehydration set point of 20 percent of body weight loss is recommended to represent victim death.

Only the initial mortality equations from the UP SAR Victim Empirical Survival Model should be factored into the PSDA output at temperatures below 15 ºC (59 ºF) during the first hour of immersion.

The tool should display the recommended MOIST for the ambient SST. The MOIST may provide critical guidance at water temperatures above approximately 15°C (59 ºF) where the model may predict that the victim has reached thermal equilibrium with the environment without reaching either a fatal core temperature (at 120 hours) or a fatal dehydration level (at 240 hours).

4.2 Functionality of the Guidance Application

The following functionality is recommended as the best combination of simplicity and utility that meets user needs. A graph will provide a visual summary of the range of possible outcomes against other information such as times of darkness. The GUI represented in Figure 3 will provide users with those functions they indicated were most important.

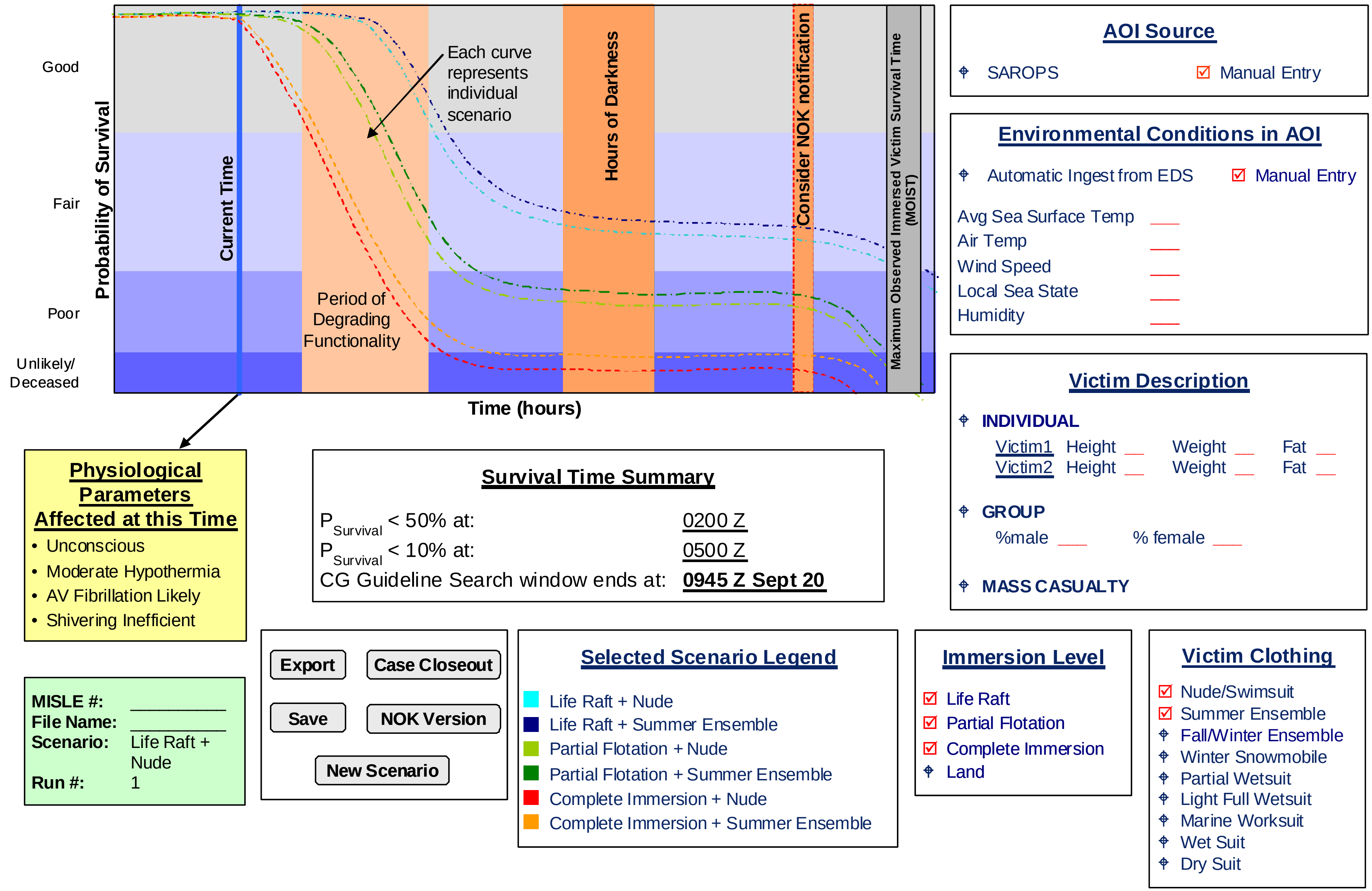

Figure 3. Graphical user interface.

4.2.1 Environmental Conditions in AOI

Environmental data will be automatically ingested by the EDS as a default option. The parameters will include SST, air temperature, relative humidity, wind speed, and wave information. In the event that conditions reported on scene vary significantly from automatically ingested data, an option will be given for manual entry of data. The geographical AOI for environmental data will be obtained from SAROPS or entered manually.

4.2.2 Clothing Options

Victim information summaries will describe victim STs for worst-case, most-likely, and best-case clothing scenarios. Discrete summaries will be displayed for each clothing ensemble selected. Independent runs must therefore be made for the victim group selected. For example, if summaries are desired for three ensembles (e.g., nude, worksuit, survival suit) for a victim pool of 100 persons, then 300 model runs will be required.

The clothing ensembles will mirror those provided in the USARIEM PSDA. The corresponding insulation values range from 0 Clo for nude or swimsuit to (1.01) Clo for a victim wearing a dry suit with double-pile insulation and a vest (1 Clo = 0.155 meter^2 * ºC/Watt).

The user will enter a clothing selection sub-menu and pick out the ensembles desired. The ensembles selected will be displayed on the summary screen.

4.2.3 Immersion Levels

The immersion scenario can have larger influence on the survival of the victim group, so alternate immersion scenarios should be shown independently. The selection and display of immersion information will mirror those for clothing. The user will enter a sub-menu and select the desired immersion scenarios. After the user completes the sub-menu, the summary information (scenarios selected) will be displayed on the summary screen.

4.2.4 Victim Description

The GUI (Figure 3) will account for three scenarios related to the number of victims:

1. A small number of victims with significantly different physical characteristics (e.g., a large man and a small boy).
2. A small number of victims (from a few people up to around 10) involved in a recreational boating or smaller fishing boat case, where only partial descriptions of the victims are available (e.g., small man, large man, small woman). In this case, the time required to discretely and accurately describe each victim may be excessive in relation to the benefit of understanding their $P_{Survival}$.
3. A large number of people involved in an incident, such as ferry, cruise liner, or large fish processing vessel sinking (number of victims could range from the twenties to hundreds).

Before entering victim data, the user will indicate whether individuals with specific heights/weights or groups will be identified by clicking on a button identifying whether (1) individuals, (2) groups, or (3) pre-set mass casualty scenarios will be identified.

Victim descriptions will start with height. A suggested approach is shown in Table 3. Two tables will be needed, one for males and one for females (only the male table is presently shown). For victim group scenarios (1) and (2), either the '# victims' or 'Probability of victim occurrence' rows will be filled in (in red below) for males and females. If scenario (1) has been selected (i.e., should be fewer than three to four victims), the user must be queried for specific weight information by the software. Body fat will be designated as low, medium, or high. For scenario (2), the software will generate a group of victims with heights distributed as defined in each row. Based on USCG HQ input, the individual victim heights may alternately be either in the middle of the range or randomly selected from the height range (row 1). Victim weights under scenario (2) will be randomly selected by the software. For scenarios (1) and (2), the software will generate a pool of victims (e.g., 100) whose physical characteristics are randomly varied around the values entered in the tables by the user. For the example in Table 3 where the number of victims has been entered by height category, the software will develop a pool of around 100 males in seven groups similar to each of the victims.

For the mass casualty scenario, pre-determined templates, created either by the software designer during software development or by a utility provided with the software, will be applied to the tables. The scenarios will contain percentage compositions by gender (i.e., % male, % female) and height distributions within each gender category (represented by low (L), moderate (M), or high (H) for each column). At the end of this step, the software will have the information needed to know how the heights of the victim group are distributed. The software will generate a pool of victims (e.g., 100) whose physical characteristics are keyed to the characteristics contained in the template.

Table 3. Group victim height selection template (data entered by the user are shown in red).

Males (100) %	**Height range**	<64"	64" – 67"	67" – 69"	69" - 72"	>72"
	Height category	Very Short	Short	Medium	Tall	Very Tall
	# victims	**1**	**2**	**3**	**0**	**1**
	Probability of victim occurrence	**L**	**H**	**H**	**L**	**M**

The body mass index (BMI) will be calculated as follows:

- For victim scenario (1), the software must provide a means for manual entry of each victim weight.
- For scenario (2) and (3), the software will make a random selection of weight, based on the probability density distribution of weight for a given height range in the general population (Jackson, et. al., 2002). Optionally, data for relational averages of height and weight could be derived from population studies in the United States (McDowell, et al. 2005).

4.2.5 Model Run Overview

As a starting point during initial model development, we recommend that software developers begin with a total of 100 visualizations of the victim group. For example, if two victims are involved in a case, the model would develop 50 representations of each victim, with heights and weights varying around the estimates provided. This pool of 100 victims would then be dressed in each of the clothing scenarios. If three clothing ensembles were selected, a total of 300 representations would be considered. If two immersion scenarios were chosen, the number would then expand to 600, representing the product of 100 independent victims and six scenarios. For this example, six population $P_{Survival}$ curves would be presented on the summary chart.

4.2.6 Victim $P_{Survival}$ Summary Screen

The victim summary at the top left of the summary screen will contain the following:

- Times that will be referenced to Greenwich Mean Time (Z).
- The reference time (origin of the graph) that will be the estimated start time of the incident.
- A sliding vertical line or bar that will represent the present time; it may also be moved into the future or past to describe future or past conditions.
- An area depicting the time range when the victim's condition is deteriorating for each immersion (neck, partial, dry) scenario. The deterioration time will start when the core temperatures of individuals in the group drop to the 34 °C (93 °F) threshold.
- A depiction of night and day periods.
- A vertical time bar to prompt the user that NOK notification may be appropriate.
- Summaries of victim group survival probabilities for each clothing and immersion combination; alternately, the software will provide the user with the option of selecting a subset of curves to display.
- A vertical time bar associated with the MOIST. Reference to this time will state that it represents the time beyond recovery of survivors for the observed conditions and is not to be construed as direction to ACTSUS.

The sponsor requested that a qualitative summary of victim survival probability be used in the summary of $P_{Survival}$ vs. time in Figure 3. In accordance with the sponsor's recommendation, the ordinate (y) axis of the victim should be scaledscaled as follows:

- For $P_{Survival} > 0.8$ 'Good'
- For $P_{Survival}$ between 0.5 – 0.8 "Fair'
- For $P_{Survival}$ between 0.2 - 0.5 'Poor'
- For $P_{Survival}$ between 0.05 - 0.2 'Unlikely'
- For $P_{Survival} < 0.05$ 'Deceased'

Calculation of Victim Population $P_{Survival}$

At the completion of the steps outlined above, the environmental scenario, the victim pool, clothing ensemble, and immersion level will have been defined. The software will then calculate the STs of the distributed victim population through a succession of logical 'do' loops.

The PSDA model examines only the effect of core hypothermia on the victim pool. The UP SAR Victim Empirical Survival Model provides a statistical description of the impact of initial immersion of the survival of the victim pool within the first hour of immersion at temperatures below 15 °C (59 °F). The initial survival equation provided in McCormack, et. al., 2008 (shown in Figure 4) will be used to calculate the effect of initial immersion mortality on the core victim group for this condition. The software will calculate $P_{Survival}$ at appropriate (e.g., 15 - 30 minute) intervals, and apply this time-varying probability to survival of the victim pool during the first hour of the simulation to account for the effects of initial immersion mortality. The survival probability from the equation at the 1-hour time will be applied uniformly to subsequent $P_{Survival}$ estimates for each victim pool-clothing-immersion combination obtained from PSDA.

Figure 4 expresses the probability of survival as a function of elapsed time in the water (t) and ambient water temperature (Temp). Each curve in the figure shows the trend in survival probability (for all victim descriptions) with temperature.

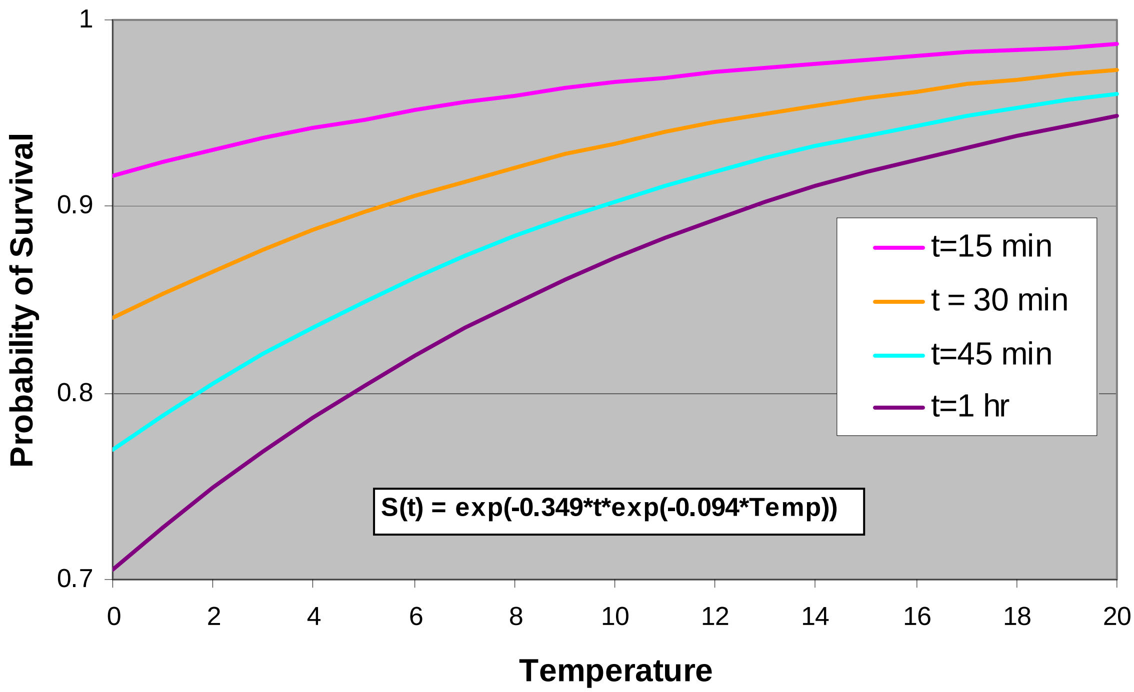

Figure 4. Initial survival relationship from McCormack et al. (2008).

4.2.7 Calculation of Maximum Recommended Search Time Limit

The project has developed an equation for estimating the MOIST for victim search that is based on all available victim data from the UKNIIS, the USCG, and other sources developed during the course of this project. MOIST is expressed as a function of the ambient SST by the following relationship:

MOIST (hrs) = 5.75*exp(0.1*SST), where SST is in degrees C.

The MOIST curve (Figure 2) is based on a subset of twelve survival cases that span the range between 2 °C - 28 °C (36 °F - 82 °F). The curve is derived from the log-linear regression on these points, with an upper confidence interval (95 percent) added based on the variance of the series. This relationship encompasses all but one of the nearly 2100 documented victim immersion cases known to the USCG. This curve therefore incorporates the available information on the survival of immersed victims. Its major limitation is that it only describes the survival of immersed victims.

4.2.8 Physiological Condition of the Victim(s)

Information on the present expected condition of the victims will be displayed under the shaded area of decreasing functionality on the $P_{Survival}$ screen (Figure 3) in a pop-up box listing the physiological parameters associated with degrading functionality at these times. This will include unconsciousness, delirium, cardiovascular irritation, etc.

4.2.9 Function Buttons

Following is a list of recommended buttons and their functions.

Table 4. Recommended buttons for the GUI and their functions.

Button Name	Function
Export	Provide a mechanism for the automated transfer of information to the CG MISLE system.
Save	Store the summary developed in a recallable format to allow other cases or other scenarios to be examined.
Case Closeout	Provide the opportunity for the USCG to add to its available information on victim survival by requesting information from the user once the case has been concluded. We recommend that for the initial version of the guidance tool, the following information be included: 1. MISLE number 2. Initial time reported 3. Initial and final positions, entered automatically from SAROPS 4. Duration of victim immersion (hours) 5. Victim outcome (survived/deceased) 6. Environmental data (sea and air temperatures, winds, waves), entered automatically from the main screen 7. Victim age 8. Victim height 9. Victim weight 10. Victim clothing 11. Victim medical summary; allow for entry as a text file to allow pasting of information from emails, etc. 12. Responder name and contact information It is recommended that a table format be provided for items 4 - 10 to allow the efficient entry of information on multiple victims.
NOK Version	Link the user to a cleaned-up version of the data in the GUI so that it is suitable for presentation to the NOK during notification.
New Scenario	Open up another window while saving the victim data already entered into the model, allowing the user to conduct excursions such as different clothing parameters and compare results.

4.3 Actions Needed to Support Future Improvements in Survival Knowledge

We recommend that CG-534 address the information gaps by implementing processes to collect **victim exposure time and victim outcome**, **victim medical condition at time of rescue, with concurrent environmental data.** This information should be collected as circumstances permit, in a manner that does not interfere with care provided by the responders. This information should be collected and recorded before the victim is delivered to other responders by the CG.

4.3.1 Improve SAR Victim Documentation

Basic information on the victim and incident should be recorded for cases where the victim either involuntarily left land or a vessel, or was unable to return to land or the vessel following immersion (e.g., swimming, diving, wind surfing incident). This recorded information should only be that which can be readily obtained through victim interviews or basic monitoring conducted by rescue personnel before the victim is transferred to shoreside agencies. No effort should be made to contact the hospital or civilian rescue personnel for survivor information.

The information in Table 5 should be incorporated into the case closeout summary. We recommend that the summary be completed prior to case closeout. Only information available during the prosecution of the search should be included in the summary; however, some effort is required of rescue personnel, particularly the rescue swimmer, to obtain victim height, weight, age, and clothing. The efforts would only be made as circumstances permit; in other words, that the victim is responsive, and the rescue swimmer is not otherwise engaged. We recommend that this information be reviewed for completeness during case closeout to ensure that any available information be included for the case.

Table 5. Incident data recommended for collection following rescue.

1.	Case number (MISLE number)
2.	Date/time incident was initially reported
3.	Responder name and contact information
4.	Activity that led to accident (ship/boat/aviation accident, swimming/diving, aquatic sports accident, suicide attempt, fall into water, influence of drugs/poisoning/disease
5.	Time that victim(s) went into the water (based on surviving victim interviews)
6.	Environmental data (sea and air temperatures, winds, waves)
7.	Victim gender, age, height, weight
8.	Victim clothing and PFD use
9.	Initial position(s) of victims and source of the position information, based on interview of surviving victim and other sources (Automatic Identification System (AIS), emergency position-indicating radio beacon (EPIRB), etc.)
10.	Significant events during the immersion (whether and when immersion status changed; e.g., raft overturned, PFD failure, came ashore)
11.	Recovery time and final position of victims reported by rescue vessel
12.	Duration of victim immersion (hours) (if initial and final times are not known)
13.	Victim outcome (survived/deceased); also, • Were they shivering when rescued? Did they shiver uncontrollably? • Did they feel drowsy or lose consciousness? • Were their arms/legs/hands/fingers numb?
14.	Victim medical summary; allow for entry as a text file to allow pasting of information from emails, etc. • Level of consciousness (LOC), alert verbal pain unresponsive (AVPU), vitals, and time of assessment • Injuries • Evidence of drug/alcohol use • Victim temperature and measurement method (e.g., tympanic) • Significant post-rescue medical events (e.g., loss of consciousness, cardiac arrest)

We have recommended incorporating victim data collection to the Case Closeout function button when the guidance tool is implemented. The summary data would be stored in an electronic format and location suitable for periodic summary by the Office of Search and Rescue.

The Emergency Medical Treatment Report, CG 5214, is presented in APPENDIX D. It contains a significant amount of information that is pertinent to the advancement of physiological knowledge about SAR victims. These sheets are periodically completed by the rescue swimmer during rescues and are stored in paper form, typically at air stations. Our attempts to access samples of completed forms were unsuccessful. The incorporation of a computer-readable version of these sheets into the case closeout database, perhaps through the use of personal digital assistants (PDAs), may facilitate easier data entry while providing a means for the automated entry and subsequent analysis of victim data. This would substantially improve the documentation of the consequences of immersion and exposure on humans. We recommend that CG-534 investigate this opportunity with the CG legal and operational medicine communities.

We further recommend that CG-534 work with CG operational medicine to revise the Emergency Medical Treatment Report to include the victim parameters in Appendix D. We also recommend that the information collected on patient vital signs on the CG 5214 form be reviewed against other sources (e.g., references provided in Appendix A and Section 3 of SAIC (2008)) to improve the qualitative assessment of victim thermal conditions.

We finally recommend that CG-534 maintain knowledge of applied research and technologies by other agencies that may be applied to this mission. Recent technological innovations include compact wireless cardio-thermo-physiological monitoring devices developed by the U.S. Army for monitoring of war fighter trainees. These devices may have a place in the monitoring of SAR victims following rescue, with minimum effort by rescuers.

4.3.2 Improve Training of SAR Planners

We recommend that development of the software and functionality for the new victim survival guidance tool be supplemented by development of an adequate reference document on its theory and application, and that a training module be developed for incorporation into the SAR School curriculum.

4.3.3 Improve Coordination and Information Sharing with Federal and International Partners

The goal of obtaining SAR victim data provides CG-534 with an opportunity to pursue its program objective to maintain a world leadership position in maritime SAR. We recommend that CG-534 work with its federal and international partners to establish standardized data collection and sharing agreements. The collection of immersed survivor data continues in the UK. We believe that the experience and knowledge held by the UK makes them a valued participant in this process.

4.3.4 Expand Understanding of Bridge Jumper Case Outcomes through Improvements to Documentation

The requirement for improved guidance on the survival of bridge jumpers was raised by several districts during interviews and during the Coast Guard User Workshop. We recommend adding the following questions to the victim summary sheet to facilitate a preliminary investigation of this issue:

- Height of the bridge above water where the jump occurred
- Accounts of victim condition after entry into the water
- In the victim summary text field, an emphasis on evidence of drug and alcohol use, and victim condition following the jump

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APPENDIX A. REQUIREMENTS SOURCES AND DISPOSITION

Table A-1 traces each suggested requirement to its source, and describes the disposition of each item as a result of the review by the SAR and physiology/modeling SMEs.

Table A-1. Requirements traceability matrix.

ID	Description	Source	Disposition
1	Predict survivability of a PIW immersed with head above water	Existing Capability	Accepted
2	Provide solid supporting information but not dominate, or increase the difficulty of, the decision to continue or suspend a search	Technical Panel	Accepted
3	Incorporate survivor, experimental, and modeled data to increase user confidence and range of applicability including the ability to base decisions regarding asset allocation on results of the model	Multiple SAR controllers	Accepted
4	Update parameters to accommodate changes in terminology	Standardization (STAN) team: Senior Command Duty Officer (CDO)	Accepted
5	Use core temperature of 25 ºC (77 ºF) as the victim's survival limit for cold exposure resulting in hypothermia	Technical Panel	Accepted
6	Use 20 percent loss of body weight to define the victim's survival limit for dehydration cases that do not involve immersion to the neck	Technical Panel	Accepted
7	Apply tool to maritime SAR cases involving victims in the water and victims in survival craft (excepting witnessed submersions)	Existing Capability	Accepted
8	Define victim survival based on victim core hypothermia	Existing Capability	Accepted
9	Define victim survival based on victim percent dehydration	R&DC	Accepted
10	Provide ST guidance based on analyses developed from historical event data to describe expected victim ST	Multiple SAR controllers	Accepted
11	Employ GUI that makes use of pull-down menus, automatic data download, radio buttons, and pick lists to expedite operator input	CG-534 Staff	Accepted
12	Validate algorithms and outputs against a data base developed from mathematical equations and include in an application describing heat transfer from the human body to an environment (water or air), ultimately determining the time of heat transfer to a critical core body temperature; the application will have been reviewed in scientific literature journals	Technical Panel	Accepted
13	Provide ACTSUS decision makers with an explanation of scientific rationale and processes behind the tool's functionality so they will better understand the limitations of the model	Technical Panel	Accepted
14	Provide a "deterministic" model with the option of selecting a $P_{Survival}$ output capability as a probability distribution; include a stochastic excursion (stochastic processes are non-deterministic, in that the ultimate outcome cannot be guaranteed by educated hypothesis)	Technical Panel	Accepted
15	Assume that the victim can maintain an open airway	Technical Panel	Accepted
16	Assume flotation assistance and/or PFDs are available to and used by the victim	Technical Panel	Accepted

Table A-2. Requirements traceability matrix (Continued).

ID	Description	Source	Disposition
17	Account for the physiological effects of body core hypothermia on the victim	Technical Panel	Undecided
18	Incorporate air and water temperature information, encompassing the range of values encountered in Coast Guard areas of responsibility	Existing Capability	Accepted
19	Provide a means to quantify the condition of the sea surface (e.g., calm or rough sea state) based on environmental data products (e.g., operational environmental models or real-time data from remote surface buoys) that will allow the calculation of victim heat transfer coefficients based on sea surface turbulence	Existing Capability	Accepted
20	Make the tool automatically ingest environmental data in electronic format (e.g., EDS) or allow for manual input of environmental data: water temperature, air temperature, and sea state	Technical Panel and CG-534 Staff	Accepted
21	Automatically convert inputs/outputs in degrees Celsius to Fahrenheit and vice versa	SAR Command	Undecided
22	Incorporate information on victim clothing	Existing Capability	Accepted
23	Incorporate information on victim gender and morphology	Existing Capability	Accepted
24	Allow the user to enter case data (date, time, MISLE number), environmental data, and victim characteristics in a single window	Technical Panel	Accepted
25	Allow the user to develop and apply pre-set scenarios for a case (including a default victim for cases where specific information and parameters are unknown)	Multiple SAR controllers/SAR Command	Accepted
26	Account for the time the victim has spent in the water	Policy	Accepted
27	Account for and calculate the physiological effects of dehydration on the victim	R&DC (initial project meeting)	Accepted
28	Account for depth of immersion (to the neck) and/or degree of wetness in terms of percent of body directly exposed to the ocean surface	Existing Capability	Accepted
29	Process case input parameters using deterministic and statistical models, as appropriate for conditions, to derive victim survival information	Technical Panel	Accepted
30	Allow the deterministic model to define both the "victim" solution based on the best estimate of the inputs, and a "probability of survival $P_{Survival}$ " solution based on random variations of victim input parameters (e.g., variations of height, weight, and clothing)	Technical Panel	Accepted
31	Incorporate a recalculate function to allow the user to change one or more input parameters and re-run the case	Technical Panel	Accepted
32	Allow for several scenarios to be run on various victim parameters if detailed victim data is not known or is unavailable	Multiple SAR controllers	Accepted
33	Provide output in GUI form showing victim core temperature and dehydration data from the deterministic model over a time continuum	Technical Panel	Undecided
34	Include predicted ST in the output based on the range of expected STs derived from variations in victim characteristics, and the MST based on historical data	Technical Panel	Accepted
35	Include a graphical summary of victim probability of survival $P_{Survival}$ as a function of time based on the randomly varied victim inputs	Technical Panel	Accepted

Table A-3. Requirements traceability matrix (Continued).

ID	Description	Source	Disposition
36	Allow users to run multiple scenarios and display their output simultaneously	Multiple SAR controllers	Accepted
37	Process a time window of up to 120 hours (90 hrs + 33% MOS)	R&DC	Accepted
38	Display the input parameters in the output window	Technical Panel	Accepted
39	Provide a summary report containing all input parameters and output data from each run	Policy	Accepted
40	Produce the final report in a format that can be ingested into the MISLE data base	Multiple SAR controllers	Accepted
41	Include a hyperlink function which leads controllers users to a simplified version of the graphic output for NOK presentation	SAR Command	Undecided
42	Additional clothing parameters	Multiple SAR controllers	Rejected: current options deemed sufficient to cover array of clothing options
43	Stranding on land or in boat	District 8 (New Orleans): Command Center (CC) Supervisor	Rejected: current model addresses scenarios by providing input of "levels of wetness"
44	Mental state of the PIW	District 5 (Norfolk): SAR Specialist	Rejected: not an objective factor to be incorporated for modeling
45	The will to survive	SAR School staff, District 5 (Norfolk): SAR Specialist, District 13 (Seattle): CDOs and Training Officer	Rejected: not an objective factor to be incorporated for modeling
46	Visual witnessing of the PIW going below surface and not returning – drowning	District 7 (Miami): Senior Duty Officer	Rejected: Policy issue, not for inclusion in model
47	Possibility of food, water and cover	SAR School	Rejected: would require higher level of sophistication not possible at this time, would make model too complicated.
48	Take into account bridge jumpers or the terminal velocity of person at a specific height	District 5 (Norfolk): SAR Specialist, District 9 (Cleveland): Assistant Chief of Response	Rejected: Requires entirely separate model

Table A-4. Requirements traceability matrix (Continued).

ID	Description	Source	Disposition
49	Alcohol consumption and its impairing effect	District 5 (Norfolk): SAR Specialist	Rejected: not valuable to the model. Not enough data to support modeling of how alcohol impairs swimming ability. Experimental evidence shows no significant cooling effect
50	Incorporate information on victim age	Existing capability	Rejected: U.S. Army mode developed determined that age is not a necessary independent variable for resolving body fat layer thickness.

APPENDIX B. COLORADO SPRINGS MODEL AND DATA PRODUCT EVALUATION WORKSHOP MINUTES

Workshop Minutes (Final)

Enterprise Solutions Division
23 Clara Drive, Suite 206
Mystic, CT 06355-1959
Contract No. HSCG32-05-D-R00010
Task Order HSCG32-08-J-100043
Control No. SAIC:001:TM:0002:043:001/-(U)

26 September 2008

Subject: Survivability of Distressed Mariners: Victim Survival Guidance Tool Development Workshop
Date(s) Held: 21-22 August 2008
Location: Colorado Springs, CO
Attendees: See Enclosure (1)

Workshop Minutes: August 21, 2008 (Day 1)

Introductions: went around the table.
Mr. Turner: gave background on project.

- Stand-alone product and ability to incorporate into SAROPS are key importance.

Requirements Discussion (Dr. Parker)

Brief overview of requirements

- District Command, not rescue swimmers themselves, expressed disinterest in having swimmers or platform personnel collect information at rescue.
- Question about decision not to talk to PIWs; some found PIW data to be very instructive, others noted it can be misleading because perceptions and memories can be affected by trauma.
- Use of AED on flights to collect medical information from victims suggested.
  - USARIEM still working on Physiological Status Monitor (Castellani)
- **Most important data points were: age/gender/ morphology, PFD, water temperature, air temperature. Most difficult data points to assess were: body morphology and levels of clothing.**
- Some victims have died at the time of rescue. The rescuer's attitude and tone may account for victims "giving up" the struggle to survive. Victims should be encouraged to keep fighting for their survival. (Tipton)
- Idea of increased public awareness needed for proper clothing and PFD in certain areas. Must make PFDs attractive to get people to wear them. Data from UKNIIS can help provide evidence for publicity campaigns. (Tipton)
  - But need to make information attractive; e.g., graphic representations.
- Suggested that model should assume PFD use so as not to suspend search prematurely; assign those parameters for morphology, fitness, will-to-live, etc. that will give best chance at survival.
  - Flip-side: model needs to give SAR planners an idea of how quickly they need to respond based on victims' real chances of survival; i.e., do they have time to assemble the SRUs and plan, or does someone need to get out there immediately.
  - Summary of shortest to longest recorded survival time: might be more useful, but also potentially problematic given the wide disparity that might arise from best to worst case scenarios. (Tikuisis)

USARIEM PSDA Presentation (Dr. Xu)

PSDA in development since 2006 to determine how long victim can survive.

6 cylinder model = central blood pool, 4 tissue layers, and clothing layer
Central temperature = core + fat + muscle → controls metabolic rate, tissue activity

- Key features of PSDA:
  - Considers both hypothermia and dehydration as survival factors.
  - Predicts prolonged survival time in water immersion > 80 hours.
  - Includes two independent methods for dehydration estimation.
  - Includes stochastic options.
- PSDA does not output probability of survival, though it is computed within the engine.
- Higher female metabolic rate: possibly b/c higher fat content? May need to re-do experiment with all females to include and modify equation. When matched for physical attributes, females cool more quickly than males due to lower metabolic response and greater surface-area-to-mass ratio.

<u>However, the average female has about 10% more body fat than the average male so, on average, males cool faster than females. (Tipton)</u>

- Factor in acclimatization? People living in cold environments likely to cool more quickly. They have a "hypothermic" adaptation to cold, in which the shivering response is diminished and thermal comfort increased. This habituation is specific to the deep body temperatures experienced; when body core temperature falls below that previously experienced, the metabolic response to cold (shivering) returns to unhabituated levels. (Tipton)
    - Study in 1930 on acclimatization in Aborigines found that those who lived in cold environments did better in cold but, after going beyond the 1º drop in temperature, metabolic response returns to normal levels.
    - Person adapted to cold will have longer reserve for shivering (because they do not shiver as much), and can tolerate lower core temperatures and have lower gradient for heat loss.
    - But this applies ONLY to people who habitually drop core temperatures not, for example, Alaskan fisherman who don't ALWAYS live in cold.
- Environmental data is input manually now, but could be imported from the CG Environmental Data Server (EDS) in the future.
- Do the very young shiver? Model only takes adults into account.
- Coast Guard needs to select certain specifically desired clothing options that USARIEM can test for insulation value.
- **<u>Users need better explanation about what Modeler means by sea state; i.e., rough seas mean different things to different people (simple explanation is enough).</u>**
    - Should we be assuming calm water again for everyone, so as to assume longest possible survival? Again rebutted with need for model to guide SAR planners in how long and when to start search, not just best case scenario for victim.
    - What about transient immersion; e.g., waves washing over head could result in drowning from incapacitation at core temperature above lethal.
- **<u>Need to have user/developer meeting so language in model is user-driven.</u>**
- Users need just one interface, with more than one model behind it, to prompt them though several questions that will choose the appropriate model for them to use.
- **<u>Assumptive analysis for shivering, death, etc. What is the impact of over or under assumption? Would be revealing to know what model parameters are very important, what are not (sensitivity analysis).</u>**
- Shivering endurance isn't clear beyond the known association with heat loss unbalanced with metabolic rate in very cold. We have no clear idea how long people can shiver because the body switches between different energy sources; however, researchers have found a modeling construct (proposed by E. Wissler) that appears to predict shivering endurance quite well. (Tikuisis)
- There is a psychological factor; cannot get caught up in core temperature alone.
    - Example of Rats and Island experiment "Learned helplessness."
- Incapacitation correlates to peripheral (muscle and nerve) temperature more than core temperature.
- The inclusion of a feature to account for the influences of swimming/exercise might make model too complicated; but can you justify ignoring exercise? People have been known to swim to shore.
    - If evidence of no people at incident site, could apply swim failure model.
    - Rate of heat loss is lower with leg-only swimming compared to arm or arm/leg swimming. Rate of heat loss from arm or arm/leg swimming is higher than from staying still. (Tipton)
- Conduct a sensitivity analysis to look at variance in cessation of shivering.
    - Roll-off starts at 32 ºC (89.6 ºF) and is assumed to cease at 30 ºC (86 ºF) in a smoothly decaying function. (Tikuisis)

 - o The cessation for shivering at 32 °C (89.6 ºF) comes from the anesthetic literature, which is less convincing than evidence from acute hypothermia cases. (Tipton)
- Need to make clear that this tool is intended to be one of many factors in the decision to suspend; three different models would be OK, but not great for users.
- The group's consensus was to populate the tool with a federation of models from which a decision algorithm would decide the most appropriate for user display. (Tikuisis)
- The ability to accurately estimate survivability is limited by the accuracy of information from the reporting source. The source may not know, or may not be willing to divulge, critical information (intoxicated boater).
    - o The completeness of information available on the victim can make a big difference in the survival time estimates from the model.
- The victim set points (core temperature and dehydration level associated with victim death) can easily be changed in PSDA.

CESM Presentation (Dr. Tikuisis)

CESM Model is 1 cylinder that is divided into 2 adjoining cylinders whose lengths are related to the level of water immersion (from neck level to no immersion). The cylinders have clothing, skin, fat, muscle, and core layers. CESM is focused primarily on death due to hypothermia. Survival time is based on a core temperature of 28 ºC (82.4 ºF) that was agreed upon by SMEs at a UK workshop held in the 1990s (PSDA uses 30 ºC (86 ºF)). A functional time (at a core temperature of 34 ºC (93.2 ºF) is also provided to describe when the victim loses the ability to effect self-rescue. This condition is related to the loss of cognitive function, not motor (e.g., arm/hand) function. CG currently using CESM 2.2, but the developer has version 3.0 ready for deployment. Version 3.0 includes the option of a stochastic prediction, which displays the probability of survival (e.g., a 75% survival probability at time 'x' is interpreted as either 75% of the target population is expected to still be alive or that the probability of survival for a single individual is 75%).

- Prediction confidence improves with greater knowledge of the input variables.
- Re-setting the lethal threshold for death by hypothermia to a lower value than 28 ºC (82.4 ºF) (e.g., 25 ºC (77 ºF)) is a simple line change in the model code; this will lengthen the predicted survival time.

A Proposal for a Maximum Search Time Guideline (Mr. Turner)

- Mr. Turner discussed the collection of victim data for the development of the new guidelines, and presented a proposed guideline for the maximum search time that is based on the ambient sea temperature (SST). Some points raised during this discussion were that:
    - o The CG survival database was synthesized from three tasks under the R&DC project that included the UK National Immersion Incident Survey (UKNIIS) database (containing 1593 data points), the CG Marine Information for Safety and Law Enforcement (MISLE) System (394 points), and from a search of the open literature (360 points).
    - o Entries in the CG survival database contain, at a minimum, victim exposure time, sea temperature, and outcome (survival/death).
    - o Cold shock/early death appears to be only weakly correlated to water temperature based on data for short-term immersions (less than an hour).
    - o Ingesting or inhaling cold water will lower the body temperature.
    - o Dog experiments (Conn, 1996): submerging in cold water showed carotid artery temperature drops within minutes.

  - Rate of cooling can result in different physiological states at the same core temperature (acute versus chronic hypothermia). Water immersion tends to result on acute hypothermia. Greater biochemical and metabolic disturbances occur with chronic hypothermia (such as may be seen in a life raft/cold air environment). (Tipton)
- The relationship is based on the log-linear trend of water temperature-survival time relationship in a subset (12) of long exposure cases where the victims were found alive, with its variability. The upper 95% confidence interval of the log-linear regression is the proposed maximum search time.
- <u>The SST-based guideline was favorably received because it provides a basis for establishing a uniform search duration standard throughout the CG.</u>
  - R&DC had found that many districts use a multiplier of 1.5 or 2 times the ST obtained from CESM.
  - This variation in district policies and practices creates potential problems for the CG.
  - If one could demonstrate that a 1.5 or 2 multiplier allows for exceptional cases, it would speak to usefulness of probabilities or distribution of expected survivability.
  - This relationship is for immersed victims only. The R&DC does not have a sufficient number of cases involving survival craft (life rafts) to establish a similar relationship for that scenario.
- The suggestion was made that the equation could be provided to planners as a provisional tool for setting search suspension time while the final tool is being developed.
- **<u>Need policy on minimum information required for guidance tool inputs.</u>**
  - The point was raised that there may be a need for a policy to define the information required to initiate the survival guidance during the initial phase of a case. This was not resolved, but the point was raised that the five statistically significant variables identified by the UKNIIS analysis would serve as the starting point is such a policy were desired.
- The issue was raised that the new guidelines might increase demand for CG assets for SAR searches.
  - The demand for non-SAR missions (e.g., law enforcement and security) is increasing: how many people are we going to save with these additional assets?
  - Mr. Turner's response was that the SST-based search guideline would likely reduce the total search effort, particularly in colder waters, by providing a better-supported guidance tool.
  - In their interviews with SAR controllers and reviews of historical cases, R&DC staff had found that media attention and requests from political or well known public figures extended CG platform search times. The longer searches were not resulting in more people being found alive.
  - The R&DC opinion was that more definitive and uniform guidance would provide SAR mission controllers with the means to curtail these extended searches.
- **<u>No guidelines yet for maximum search time - across the board.</u>**
  - Searching for PIWs in warm water is always going to be an issue if someone survives longer than we searched for them.
  - Exposure times up to 90 hours are found in the data. USARIEM was reluctant to go beyond that 90-hour point, although the USARIEM model does indicate that victims can survive longer exposure times.
  - The R&DC and USARIEM had earlier agreed that the model would provide information out to a 120-hour horizon, or approximately 33% beyond the duration of the longest-known immersion survival time. This can serve as an upper limit until it is exceeded during a case.

Workshop Minutes: August 22, 2008 (Day 2)

Introduction to Data in Recommendation Report (Dr. Parker)

- The SAIC report ("Recommendations Report Victim Set Points for Survival Model Use", dated 7 March 2008) had recommended that a core body temperature of 21 ºC (69.8 ºF) predicted for the victim would indicate 'certain' death. The discussion raised a number of points that pointed to a higher temperature.
  - Use of the 21 ºC (69.8 ºF) core temperature in water waters (i.e., greater than 21 ºC (69.8 ºF)) would necessarily lead to essentially infinite, or '> 120-hour' search times, because the victim could not cool below that point.
  - The reliability of the measurements in documented extreme cases of hypothermia was questioned.
  - There was some discussion that marine immersion cases were inherently more stressful and more difficult to survive. The victim is fragile, but the environment is dynamic, and the victim gets knocked around. The victim is therefore less likely to survive deeper hypothermia.
- The discussion covered the distinctions between marine and land cases.
  - Cooling rates are lower in air; hence the time to get to higher fatal core temperatures would be longer in air.
  - In marine cases, acute hypothermia is the principal cause of death, while on land, acidosis is also an issue.
  - Marine PIWs have likelihood of death from drowning which persons on land aren't susceptible to; this distinction is very important.
  - It was proposed that the core temperature set point can be varied with the scenario (i.e., land vs. water).
  - Left unanswered was whether new technology made survival at low temperatures more feasible.
- **From a sensitivity standpoint: how different is a core temperature of 25 ºC (77 ºF) from 28 ºC (82.4 ºF) in terms of search times?**
- This question will be examined by Mr. Turner following the workshop. In its report, SAIC suggests that, based on published cooling rates, the difference will be smaller at lower temperatures, perhaps a few hours, and will increase to many hours into days at warmer temperatures.
- In warm areas, the size of the search geographic search should control the search duration, not core temperature. (Capt. Harman)
- Can't let emotion into a decision: if below a certain temperature the person is dead, they are probably not salvageable.
  - Can use this to justify to family.
- **25 ºC (77 ºF) is a reasonable set point.**
- The SAR planners should make assumptions about life raft, exposure suit, PFD, not about the model.
- NOTE: The difference in predicted survival times for endpoints of 25 ºC (77 ºF) vs. 28 ºC (82.4 ºF) depends on the ambient temperature; i.e., the colder the water for a PIW, then the less of a difference (also consider the very real possibility of a PIW in water between 25 ºC (77 ºF) and 28 ºC (82.4 ºF), in which case the predicted survival times for endpoints of 25 ºC (77 ºF) and 28 ºC (82.4 ºF) are infinite and finite, respectively). (Tikuisis)
- Reduction of the core temperature set point will inherently reduce the safety margin added to the guidance by SAR Mission Controllers (SMCs).

  - Search times will be longer, and SMCs will tend to reduce the safety margins they apply in interpreting the guidance. They now add a significant margin of safety to the search time, typically an additional 50-100% of the CESM survival time.
  - In addition, SMCs typically add more time by extending the search to the next time of sunset.
  - Other factors, such as media attention or requests from political figures, may further extend the search time.
- The net expected effect will be to improve the uniformity of interpretation of the guidance.

University of Portsmouth Model Based on UKNIIS Data (Dr. Tipton, Dr. Tikuisis, Ms. McCormack)

- The UKNIIS was transferred from paper form into a computer database by the University of Portsmouth.
- The database now contains 1593 data points. Each point represents an incident where a person was in the water. The rescuers filled out and submitted a form containing up to 23 variables on the incident. A majority of the data points represents cases where the victim was in the water for an insufficient period of time for them to suffer the effects of hypothermia. The data set does include cases where hypothermia may not have been the cause of death.
- An initial significance test determined that five fields in the UKNIIS were significant predictors of survival probability: water temperature, water area, clothing, age, and PFD use.
- A regression analysis based on the Weibull distribution was used to produce a family of survival probability functions. The regression employs both left censoring where the person is recovered dead (the event occurred an unknown time prior to recovery), and right censoring where the person is recovered alive (the event will occur an unknown time after recovery).
- Ms. McCormack's report ("Search and Rescue (SAR) Victim Empirical Survival Model", dated February 2008) contains a series of equations built on the Weibull basis function. Discussion of the results led to the conclusion that the equations may be used within the limits of the data. These approximate limits are 14 ºC (52.7 ºF) or less and 14 hours or less.
- The discussion also covered the topic of PFD use. The influence of PFDs was very strong on expected survival; however, PFDs do not save lives due to their poor fit.
- The opinion was expressed that PFDs cannot be considered to be effective lifesaving devices unless they are fitted with a crotch strap. (Tipton)
- Victim build was judged to be a subjective term and not a significant predictor of survival probability.
- **Predictive parameters:**
  - **Air/Water Temperature: objective**
  - **Clothing, PFD, Age: could be subjective**
- The UKNIIS does not include victim core temperature data. The discussion continued on that topic to determine whether it should be incorporated into some potential future database. Temperature measurements in the field are generally tympanic (made in the ear). These temperatures were not considered reliable by the group, first because the method does not produce a result comparable to core temperature, and second because the measurement is not always performed properly.
- The counter-argument was that the tympanic measurements tends to produce a value lower than the actual core temperature. Body temperature (e.g., at death) will not be lower than the temperature value recorded.
- A discussion was held on the influence of factors such as habituation that might allow survival at lower core temperatures.

    - As an example, experimental data shows swimmers in 10 ºC (50 ºF) water, in swimsuit only, going into thermal balance at 60 minutes.
    - The counter-argument was that habituation to cold reduces shivering, but if you take people beyond the level to which they are used to being cold, they will begin to thermoregulate.
    - In other words, once people exceed the condition to which they have habituated, their response converges on that of the rest of the population.
- **The consensus of the group was that providing multiple models was generally desirable.**
    - Provide both of the model projections, as appropriate, and supplement with a statistical analysis.

Summary and Wrap Up (Dr. Parker)

General requirements from interviews: During the interviews, areas were mentioned as "candidates" for additions to the model inputs and thus "processing" to help improve the final output of the model.

Could or should the model address:

- Mental state of the PIW
    - Unanimous agreement: The model should NOT include mental state. This is a lesson learned for how rescuers address the rescue.
- Will to survive of the PIW
    - Unanimous agreement that this is the same as mental state.
- The presence of life rafts or flotation debris
    - **Agreement that this should be a module characteristic that needs to be worked out and included in the model somehow.**
    - Model would already account for hanging onto debris rather than being in raft; have levels of wetness and immersion you can apply for various kinds of debris. Model should automatically apply to chosen flotation.
- Visual accounts of the PIW going below surface and not returning (drowning)
    - Consensus that this is a policy issue. If you have a good view of the area and don't see them return to the surface, this would probably negate use of the model.
- Immersion suits
    - Already included in CESM 3.0.
    - Incorporated in the USARIEM model as a dry suit with undergarments.
- Possibility of food, water and cover
    - Covered life raft is already addressed by PSDA and CESM, but a food/water option is not included in the USARIEM model.
        - Factoring in an assumption about onboard food and water is a decision that is beyond the scope of this project.
        - If you know the individual has these items, you would extend search, but do not include these parameters in model.
    - **Need to look at tool again and evaluate where water and food come into play. May be GUI interface issue.**
        - Without water, dehydration limits survival time, but after an extended period of time, the availability of a sufficient number of search platforms to cover the expanding search area sufficiently becomes limiting. From an operations standpoint, planners would certainly want to know if a person is able to hydrate and find cover.
        - This level of sophistication might make the model too complicated right now; may be an option that will be looked at further down the road.

- Bridge jumpers as a special category
  - **This requires a new model entirely.**
  - **Study needs to be done by R&DC.**
- Victim stranded on island or in tree
  - This is already covered by PSDA and CESM with appropriate input.
- Alcohol consumption
  - Not valuable to the model.
  - Study done years ago found that there was very little/no difference between cooling in intoxicated vs. sober. Cold water negates much of the effect of alcohol. Alcohol can, by impairing co-ordination, negatively influence swimming ability. (Tipton)

General Comments on Model Use and Accessibility

- A model is necessary because the end-state is unique. A simple standard curve would have everyone dying off or every search ending at X hours; but a distribution of times that depend on the variable case is really needed, and only a model can do those things.
- The model provides information that supports planning the logistics of the search by providing a distribution of projected survival times, and distribution of survivors would impact distribution of resources.
- Controllers looking at model one by one, case by case; so presenting statistics allows them to see that the model is backed by large body of knowledge.
  - Let them look at what can happen (probabilistic approach) and what has happened (time limit for body temperature).
  - Requires definite guidance and rules so controllers don't get confused about how to use resources.
- What are the most important 5 (or 6) factors that are deterministic of ST?
  - Water temperature and air temperature (can be obtained from environmental data sources)
  - Sea State (can be obtained from environmental data sources)
  - PFD
  - Clothing
  - Age/Morphology/Gender
  - Time in water (this is not an input variable)
- Which of the above are not already in the model?
  - PFD use is not explicitly included, but is inherently assumed by the model; otherwise, would just be drowning model (not hypothermia). (Air and water temperatures are already included for partially immersed victims.) **(Need more clothing choices, according to controllers. No real agreement that this is necessary based on SME comments.)**
- Controllers wanted a product that produces a report that is easily merged into MISLE and into the final report.
  - **Accessibility of model is a Coast Guard architecture problem.** Implementation in CG dictates accessibility. Integration is not an inherent problem of the model.
  - **Incorporation of data into MISLE is probably architecture problem as well.** When CESM is integrated into SAROPS and SAROPS gets integrated with MISLE, it will allow for smart searching. But still needs to get pushed through policy.
- No one wanted media or political input to be an consideration or variable in the model.
- It is incumbent upon us to insure that the model output is understandable so that mid-level controllers can understand what was done and considered by model.

- Implementation scheme needs to keep in mind the ability to guide the decision maker so as to have actionable data for the case report. CG controllers need output that is defensible because of the underlying science.
  - Have had numerous cases come back and challenge model, but clarification of interpretation usually resolves these cases.
- There was divided opinion on the value of being able to review and see historical data.
  - SAR planners will be able to see historical data, during training (SAR School), they need to learn about how data from model was developed.
- Gaps in knowledge/information
  - Collecting medical data
    - Changing policy for platform procedure during rescue will require multiple CG1s; even if collectively agreed upon, may take over 5 years to get it through the process.
    - Would still have a problem getting just local platforms to collect information: the more complex you make it, the less likely you will get it.
    - HIPAA protection? Not for Coast Guard on platform: rescue operation not under obligation as are ambulances hospitals, etc.
    - Coast Guard CAN get data from hospitals, is allowable, but is difficult to get through hospital policy.
    - Rescue swimmers use victim checklists but the data is not used in MISLE so it is hard to obtain.
    - Would be useful at least to note if victim still shivering and level of consciousness/coma scale; but these are not pressing issues.
    - Revisited pros and cons of tympanic temperature and variance in collection techniques leading to inconsistent data.
    - We can collect height/weight, age/gender, and clothing.
    - How long must data be collected before you get enough for a useful sample size? Length may determine usefulness.
    - **Victim data SHOULD be collected but the issue cannot be resolved at this time. The group collectively agreed that this work SHOULD be conducted.**
    - **End question: will collecting this data improve how we respond in SAR cases? Might it negatively impact how we perform SAR?**

"Parking Lot" Issues

The facilitator instated a 'parking lot' to 'park' items for later discussion. At the end of the conference, the group covered these issues.

- Calm vs. rough sea
  - In general, the CG SAROPS EDS can provide sea state information for the survival tool.
  - The discussion turned to the fact that large-scale operational models and data products may not sufficiently describe local conditions, and that some means of additional data entry is called for.
  - GUI interface: user has parameters they must complete and system classifies which model to use based on that.
  - Dropdown menu or a provision for manual data entry would be worth having so that personnel on scene can enter in-situ data based on their observations at the scene.
  - **Multiple-input type module so output to module itself would have calm or rough.**
- Psychological effects on survivability

 - The group agreed that this factor should not be considered. The model should make the most optimistic assumptions about survival. Other considerations, such as this, should be factored by the SMC in the final decision.
- Policy: How to use the model
  - Policy makers should ensure the developer provides in-depth explanation of the inner workings of the tool so that users can be trained on capabilities, limitations, and appropriate use.
- Sensitivity analysis
  - The group was interested in knowing how much longer survival time is at 25 ºC (77 ºF) core temperature versus 28 ºC (82.4 ºF).
  - Modeling issue of interest to the modelers only. The sensitivity of survival time to the assumed fatal core temperature should be resolved.
- How good does the model have to be?
  - User feedback indicates that time bounds were too short to help in warm water cases. Too many warm water cases produced survival times greater than 36 hours, so the CESM model is effectively not a part of the search suspension decision.
  - A formulation that predicts a longer survival time would be an improvement that we should take advantage of.
- Excursions: best scenario vs. worst scenario
  - Users can use the model to do this; they might need training, but model doesn't need to provide this outright.
  - If would be good if some of this can be done by the model to take work off the user. A variational analysis might be of value if it provides significant changes in survival time (between ½ hour, 2 hours, 4 hours, etc.) by providing perspective on the variability of survival time.
- In a search, when should the model be run? This may be considerably different in extreme cold vs. warm environment. Models and data need not be mutually exclusive.
  - This is a CG policy topic.
- Central vs. distributed use of the model?
  - Systems end problem: SAROPS on powerful servers run remotely, not limited by PC power.
- What would an "integration" of the models look like?
  - Family of models: each model provides different information, sometimes complementary but both should be part of one parcel; might want to look at outputs from both. Have human thermal model output overlay statistical model and limit the estimate?
  - Is there a range where CESM and PSDA give the same output?
  - Which model should be used under what conditions?
    - Water temperature will determine which data source/model you are going to use (if temperature over 15 ºC (59 ºF), do not use UKNIIS).
    - Use PSDA for victims in rafts in warm air conditions.
- Use of CESM v3.0 with stochastic approach vs. the deterministic approach
  - No decision has been made to distribute this version of the model throughout the Coast Guard.
  - Version 3.0 has new data in it and is undergoing continued modification. A user's guide is also available with v3.0.
  - In essence, CESM 3.0 produces a survival probability for the victim that can be applied to an individual or group of people.

Where We Go from Here

- Assessment of the Models
  - o The group concurred that the options developed by the study were suitable.
- Core Body Temperature Set Point
  - o **25 ºC (77 ºF) core temperature is defensible if no cases of a reliably measured lower core temperature have been recorded for relevant incidents of water survival (similar to CG cases). (Tikuisis)**
    - The lower temperature set point would supplant the safety factor that users are employing now.
    - A consequence of setting critical temperature to 25 ºC (77 ºF): would it make search time at warmer temperature infinite?
      - Dehydration is still a factor in the model but after 120 hours at 25 ºC (77 ºF), dehydration not going to reach 20% for a very long time.
      - At water temperatures above 26 ºC (78.8 ºF), the model-predicted survival time would be above 120 hours for hypothermia (essentially infinite) but have an arbitrary cutoff at 120 hours for the Coast Guard (at this point have not seen survival times above 90 hours); or if you choose 25 ºC (77 ºF) policy, could state don't use thermal models in environments with over 25 ºC (77 ºF) ambient temperature.
  - o Lowing the set point could result in excessively long search times in water temperatures slightly above the set point, thought survivability below 28 ºC (82.4 ºF) is low. Dr. Whissler suggested that time spent at core temperatures below 28 ºC (82.4 ºF) can affect mortality; a person may die at a core temperature above 25 ºC (77 ºF) if the cooling rate is slow, as in a moderate environment. Shivering failure at 30 ºC-32 ºC (86 ºF-89.6 ºF) may play a role but is not well understood. There is little data available in this area. One approach to determining ST in warmer water might be to add a set time interval to the time when core temperature reaches 28 ºC (82.4 ºF).
    - **Consensus: Worthwhile to investigate what the additional time interval would be.**

Output of Model

- Users want multiple-choice screen so they can select multiple items and pull up multiple screens.
  - o Recalculation screen so can go one step back and put in additional information as it comes in
  - o Bar with current time and box showing known number/percent deceased at this temperature
  - o End point for water temperature based on historical data: no survivors found after this time (only for the data range statistical model can cover; i.e., not outside 16 ºC (60.8 ºF)); width of this bar should account for variance
  - o Not just one line so not complicated
  - o Use upper limits for survivability curves
  - o Need to get away from only a box with a number in it
- Less is MORE.
- Comments on terminology (Tikuisis):
- o CESM 2.2/PSDA are 'deterministic' models (i.e., specific output for given input).
- o CESM 3.0 has a 'stochastic' or 'probabilistic' option based on rational randomization of target population. PSDA has alternately been set up in a stochastic mode.
- o UKNIIS model (Weibull) is a 'statistically'-based prediction of incident survey data.

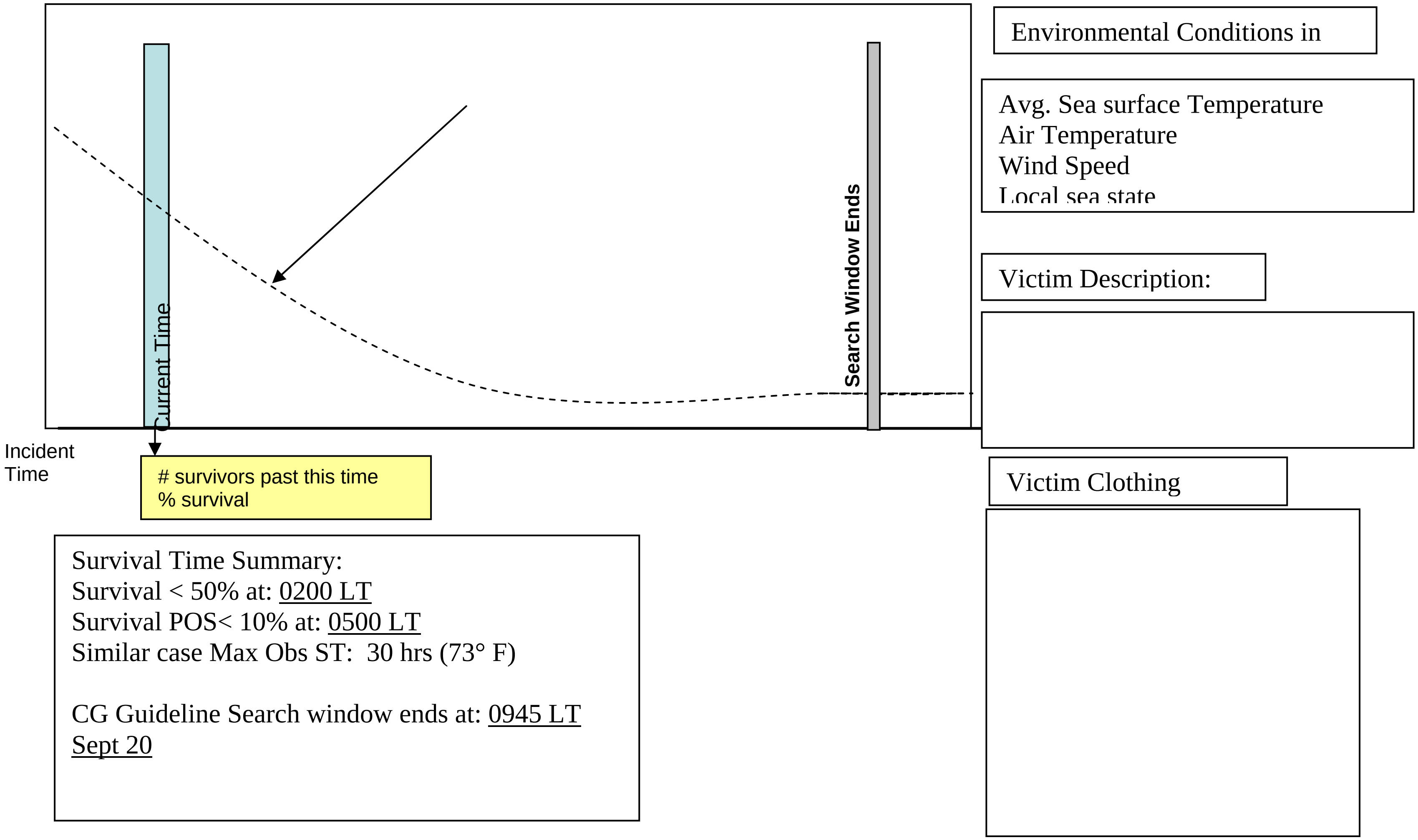

Figure B-1. Model GUI concept.

Workshop Minutes: Evaluation of Human Thermal Models for Predicting Survival Time of Accident Victims

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29 August 2008

Various human thermal models have been developed during the last half century. A brief review of the evolution of those models is presented in the Appendix. All human thermal models involve computation of transient-state temperatures within the body by solving the heat conduction equation with appropriate initial and boundary conditions. The fundamental equations of heat conduction were developed by Fourier in the last half of the eighteenth century and elegant analytical methods were subsequently developed for solving those equations. With the development of high-speed digital computers, analytical methods gave way to numerical methods, and today commercially available software is available for generating accurate solutions for geometrically complex systems. Several human thermal models have been developed using commercial software, but few details have been published. Although temperatures are computed are computed with great accuracy in those models, one wonders how well physiological factors are handled.

While the theory of heat conduction is well understood in principle, its application to human thermal models varies greatly. For example, geometry is an important factor. Since most bodily elements are cylindrical in shape, it is not surprising that human thermal models generally represent the human form as a set of cylinders, although the head is sometimes represented as a sphere. However, an important difference between models is the number of cylinders employed, which can vary from one to more than fifty. The models being considered by the Coast Guard use a small number of cylinders: either one or three for the Tikuisis model (I haven't seen a detailed description of that model) and six for the Xu model. The six elements of the Xu model represent the head, trunk, arms, legs, hands, and feet.

A second important characteristic of models is the manner in which they represent the internal structure and thermal state of the body. In Xu's model each cylindrical element is divided into four regions representing core, muscle, fat, and skin, which is the commonly used arrangement first employed by Stolwijk in 1970 (Ref. 1 in the Appendix). The model also has a circulating central blood pool that allows convective heat transfer from warm regions to cooler regions. In addition, conduction of heat from the core and muscle to skin is allowed. Since each region and central blood has a time-dependent temperature, the thermal state of the body is defined by 26 temperatures. That can be compared with more than 1,000 temperatures in more detailed models.

The amount of detail required to adequately define bodily thermal state depends on circumstances. During light exercise in a warm environment, temperature is fairly uniform throughout the body, and a small number of temperatures provide an adequate representation. On the other hand, during cold exposure, large temperature differences exist throughout the body, and it is impossible to define the thermal state in terms of a few temperatures.

To summarize, heat transfer is very well understood in principle and methods exist for accurately computing transient-state temperatures in the human body. However, the models developed by Tikuisis and Xu employ rather approximate methods that may not be very accurate. That does not necessarily preclude using either model to predict survival time, because a judicious choice of parameters can compensate to some extent for errors introduced by poor representation of geometry and a small number of computed temperatures.

Computing tissue temperature is essentially a physics problem. An equally important part of human thermal modeling is defining physiological responses to thermal stress and exercise. Even when bodily temperatures are computed with great accuracy, uncertainty is introduced into a model by inadequate knowledge of physiological phenomena. Important factors include regulation of blood flow to skin and muscle, shivering intensity and regional distribution of shivering metabolism, "shivering fatigue," and distribution of blood flow through deep and superficial veins, which affects counter-current heat transfer. Some of those phenomena, such as skin blood flow, have been studied extensively while others, such as various aspects of shivering, have been the subject of only one or two studies, which often yield inconsistent results. Moreover, most physiological phenomena have been studied only under a limited set of conditions. For example, the two principal studies of shivering during immersion in cold water employed very cold water, which leaves unanswered questions about shivering during prolonged immersion in cool water. In addition, subjects in the two principal shivering studies were immersed to the neck, but there is little information about shivering during partial immersion. Both commonly used shivering correlations define the intensity of shivering in terms of a core temperature measured in the rectum and the mean skin temperature, but it is unclear how cooling only the legs, for example, stimulates shivering. Not only is there considerable uncertainty about relevant physiological phenomena for an "average person," responses often vary appreciably for different individuals within an ostensibly similar group of people.

Observations presented above strongly suggest that a priori prediction of expected survival time represents wishful thinking. What should be done? First, it is important to conduct a careful comparison of the models developed by Tikuisis and Xu. Xu has described his model in a published paper, which is very similar to his presentation at the Colorado Springs workshop. As far as the author knows, a comparable description of the Tikuisis model does not exist in the open literature.

A comparison should be made of temperatures, metabolic rates, and predicted survival times computed using the two models. There will almost certainly be significant differences in computed core temperatures during the first two hours of immersion. What one might expect is illustrated in four figures taken from a paper published recently by Castellani, et al. (2007). The solid curve was computed using the Tikuisis three-cylinder model (although it is not clear that this is the model used in Tikuisis' survival program) and the broken curve was computed using Xu's model. Subjects walked at 0.44 or 0.88 m/s while immersed either to the neck, or to the waist.

Several observations are of interest. Behavior of the Tikuisis model is unrealistic for 0.88 m/s walking while immersed to the waist in 15^{o}C water. In the other three cases, both models predict that an equilibrium condition will be established in which the rate of metabolic heat generation balances the rate of heat loss to the environment. Although that behavior is not clearly apparent in the experimental data, it is reasonable. The practical implication of that behavior is that a victim of accidental immersion in cold water can avoid hypothermia as long as he maintains an adequate rate of shivering metabolism. Consequently, the predicted survival time is very strongly dependent on the victim's ability to shiver. Unfortunately, not much is known about shivering fatigue, which is very difficult to study in the laboratory. One study by Tikuisis, et al. yielded inconclusive results (in the author's opinion).

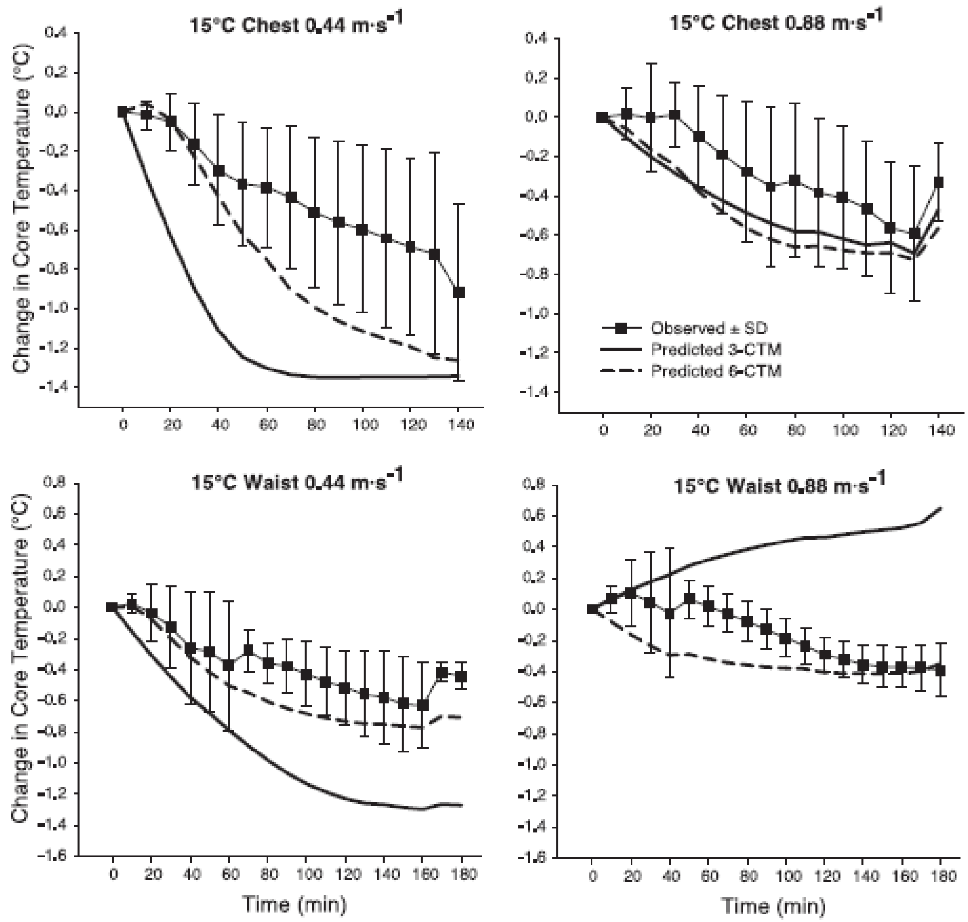

Figure B-2. Comparisons between observed and model-predicted test subject core temperatures during exercise in cold water (Castellani et al., 2007)

Xu compared expected survival times computed using his model with Molnar's data. Tikuisis may also have made such a comparison, but it was not presented at the workshop. Xu uses a different criterion for death than the one adopted at the workshop, and Tikuisis uses a criterion different from either of the others. One question that should be investigated is the dependence of survival time on lethal temperature. It may be that expected survival time increases only moderately when the lethal temperature is decreased from 28 ^{o}C to 25 ^{o}C. If a victim can establish an equilibrium state by shivering, his core temperature will remain constant until he stops shivering, after which it drops precipitously.

Computed survival times should be compared with historical data for persons in the water who are not wearing anti-exposure suits. There are several ways to construct a data-based survival curve. One way is to plot the data and draw a curve by eye, as Molnar did. Another way is to perform a sophisticated statistical analysis, as the Portsmouth group has done, and a third way is conduct a regression analysis of selected points that represent long-term survival, as Turner did. The author has a problem with the Portsmouth approach, because, although the data base contains nearly 1600 cases, there are only fifteen cases for which the survival time of unprotected persons is longer than two hours, and the longest survival time is 14 hours in 14 ^{o}C water. For some conditions, confidence limits were as wide as one hour to more than forty hours, which is difficult to interpret. Turner's survival curve is reasonable, although it needs to be modified for water temperatures above roughly 28 ^{o}C, because several reliable studies have shown that individuals can maintain a steady core temperature with only minimal shivering when the water temperature is 28 ^oC or higher. Three papers attached to this document provide useful information about short-term immersion in 28 ^oC water (Cannon and Keatinge, 1960; Craig and Dvorak, 1966; and McArdle, et al. 1984). It is also important that a survival curve be consistent with the assumed lethal temperature in that bodily temperatures will never be lower than the water temperature. Hence, if the lethal temperature is assumed to be 25 ^oC, the expected survival time is infinite at any temperature above 25 ^oC.

After a model has been tuned to provide good agreement between computed and historical survival times for an average unprotected person in water from 0 ^oC to 30 ^oC, it can be used to assess the effect of sea state, gender, body mass, percent body fat, effect of wearing an anti-exposure suit, and other similar factors. In other words, calibrate the model to a reference condition (say a person in the water without anti-exposure gear) for which the best possible, historical, data-based expected survival time has been constructed, and then use the model to assess the effect of modifying factors.

Despite their limitations models can be of value in constructing a survival curve. For example, they establish that the expected survival time is short in cold water to no one's surprise. A model might also be value in predicting survival time for water temperatures in the neighborhood of 28 ^oC, where good experimental data for one or two-hour immersions suggest that intense shivering is not required to prevent hypothermia. However, models by themselves are not capable of predicting survival time for water temperatures from 10 ^oC to 24 ^oC because of the uncertainty factors mentioned above.

Accounting for the effect of modifying factors must be done with care. For example, one effect of sea state is to increase the heat transfer coefficient at the person-water interface, which Xu mentioned in his presentation, but that is probably not the only significant effect of sea state. One would expect that a very cold individual is less likely to survive in heavy breaking seas than in relatively calm swells. Similarly, gender is an important factor, because the distribution of subcutaneous fat in females is different from that in males, and the feminine shivering response is different from the masculine response. An important factor that was not discussed is cooling of persons in a life raft. How the simple models of Tikuisis and Xu account for non-uniform boundary conditions (anterior surfaces exposed to cold air and posterior surfaces exposed to cold water through the floor of the life raft) needs to be considered.

The author would also suggest that the lethal temperature be adjusted to account for different conditions. For example, 25 ^oC may be perfectly reasonable for someone in a life raft, or on land. Indeed, 21 ^oC might be more appropriate. On the other hand, 28 ^oC below which unconsciousness is probable is more reasonable for a person in the water, especially in rough water.

It is worthwhile to consider how expected survival time (t_{es}) affects an SAR mission. While that entered discussions at the workshop on several occasions, it probably did not receive the attention it deserves. The probability that an SAR mission will be successful is the product of two probabilities, the probability (P_l) that the victim will be located and the probability (P_s) that the victim will be alive when found. Both probabilities are functions of time and the conditions of the search.

The Coast Guard has devoted considerable effort to computing P_l, which increases with the duration of the search (t). If the area in which the victim may be located is pie-shaped and the victim drifts at a constant velocity, the area in which he could be located increases as t^2. Moreover, for a given number of miles flown per hour searching for the victim, the probability P_f that the victim will be found per unit time should decrease as t^{-2}. Hence, for illustrative purposes, assume that

$$P_f = \frac{C_f}{t^2} . \qquad (1)$$

It should be noted that the Coast Guard program for predicting the path of the victim probably yields a functional form for Pf somewhat different from Eqn. 1. It is reasonable to expect that Pf for a computer-directed search decreases less rapidly than predicted by Eqn. 1. Nevertheless, Pf certainly decreases with increasing time, and the conclusions drawn from this approximate analysis should have some value.

The probability that a victim will be found in the interval from t to t + dt is equal to the product of the probability that he has not been found prior to time t and the probability that he will be found in dt about t. If Pl is the probability that the victim has been found by time t, (1 – Pl) is the probability that he is still in the water at time t. Hence,

$$P_l(t+dt) - P_l(t) = \frac{dP_l}{dt}\,dt = (1 - P_l)\,P_f\ dt . \qquad (2)$$

Eqn. 2 has a solution of the form

$$P_l = 1 - exp\left(\frac{C_f}{t} - C_0\right) \qquad (3)$$

where C_0 is an arbitrary constant.

To evaluate the constants Cf and C0 we need to make two assumptions. We will assume that the probability of finding the victim two hours after the accident is 10 percent. Note that there are some problems with the behavior of Pl as t $\rightarrow$ 0, but we won't worry about that. Also assume that the probability of finding the victim after a very long search is 90 percent. It follows from those assumptions that C0 = -2.303 and Cf = 4.4 hrs. Pl is plotted as a function of time in Figure B-3. It is apparent that for the conditions assumed in this example, the probability of finding a victim increases very little after 15 hours.

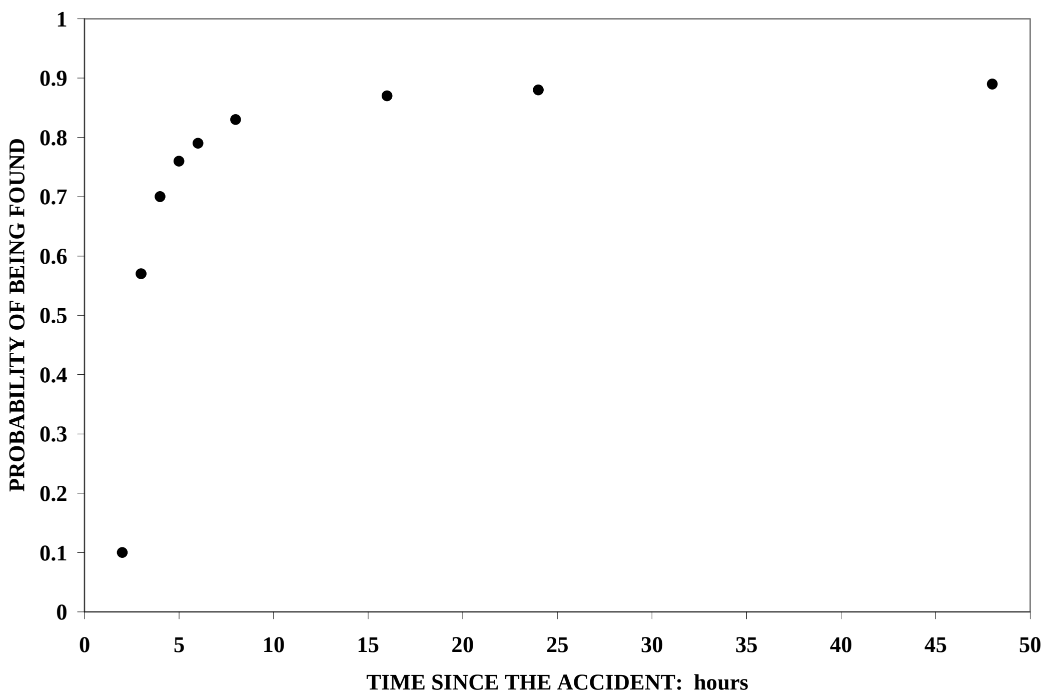

Figure B-3. Probability (P_l) that a victim will be found within t hours of the accident.

It is interesting to consider how the probability (P_f) of finding a person per hour of search time decreases with increasing time. For the particular conditions assumed in evaluating P_l, we have

$$P_f = \frac{4.4}{t^2}. \tag{4}$$

That function is plotted in Figure B-4. As noted earlier, there is a problem for short times after the accident, because the probability of finding the victim per unit search time cannot be greater than unity. Nevertheless, the points plotted in Figure B-4 illustrate clearly the diminishing return gained from a prolonged search.

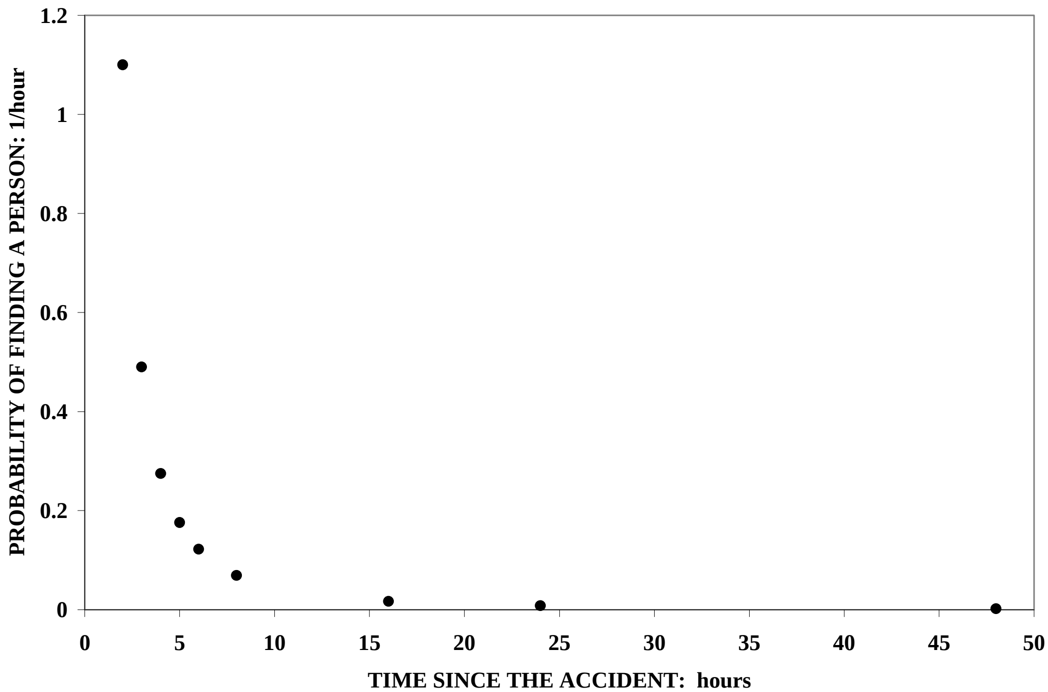

Figure B-4. Probability (P_f) of locating a victim during a one hour search t hours after the accident.

Consider the probability (P_s) of survival. Although we tended to discuss the expected survival time (t_{es}) as though it were a unique time at which death occurs, the probability of survival is actually a decreasing function of time in the water. How rapidly P_s decreases with increasing time depends on various factors, such as water temperature and sea state. Although the UK analysis (which the author has not seen) might provide a functional form for P_s, we will assume that the probability of survival decreases exponentially with increasing time. We will also (arbitrarily) define the expected survival time as the time at which the probability of survival is five percent. Then the probability of survival is

$$P_s = P_0 \, exp\left(-\alpha \frac{t}{t_{es}}\right) \tag{5}$$

in which P_0 is the probability of surviving initial immersion, and α is a constant to be determined by the requirement that $P_s/P_0 = 0.05$ for $t = t_{es}$; it follows that

$$\alpha = - \ln (0.05) = 3.0. \tag{6}$$

Now the probability (P_r) of a successful rescue can be computed. We have

$$P_r = P_l\ P_s = \ 1 - exp\left(\frac{C_f}{t} - C_0\right)\ P_0\ exp\left(-\alpha\ \frac{t}{t_{es}}\right). \tag{7}$$

Graphs of P_r as a function of time in the water are plotted in Figure B-5, again for the particular assumptions stated above. Results are shown for two cases; in one the expected survival time is 10 hours and in the other it is 20 hours. Assume that $P_0 = 0.9$ when $t_{es} = 10$ hours and $P_0 = 1.0$ when $t_{es} = 20$ hours.

It is interesting that in both cases the probability of a successful rescue peaks in less than 5 hours. For times less than 5 hours, P_r increases as the probability of finding the victim increases. However, P_l reaches its maximum value rather quickly, and for times greater than 5 hours, the probability of a successful rescue decreases as the probability of survival decreases. Since the probability of finding the victim is close to its maximum value at either of the expected survival times, the probability of a successful rescue at the expected survival time is approximately 0.9 x 0.05 = 0.045.

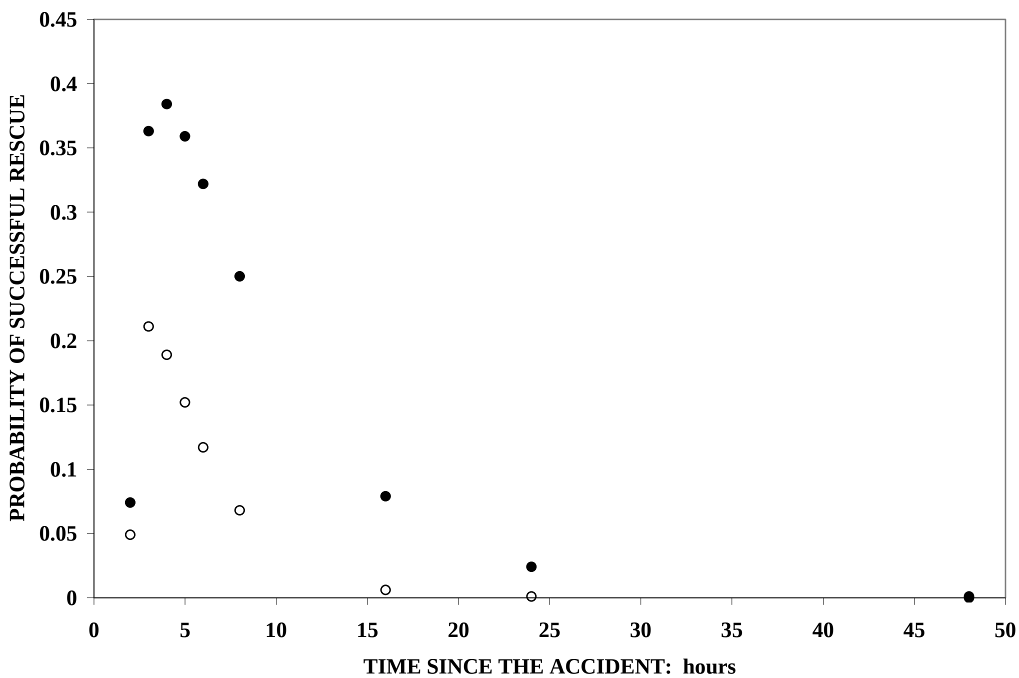

Figure B-5. Probability ($P_r = P_l\ P_s$) of effecting a successful rescue as a function of time in the water and the estimated survival time. Open circles denote tes = 10 hours and filled circles denote tes = 20 hours.

An important function in terms of terminating a search is the probability that a victim will be found alive during one hour of searching t hours after the accident. That probability is simply the product of the probability of being found during the search and the probability of being alive, Pf Ps. Graphs of that function are plotted in Figure B-6 for the same conditions as those of Figure B-5. Since Pf and Ps both decrease with increasing time, the probability of being found alive during a one hour search decreases very rapidly with increasing time in the water. Even when tes = 20 hours, the probability of finding a victim alive during a one hour search 15 hours after the accident is essentially zero.

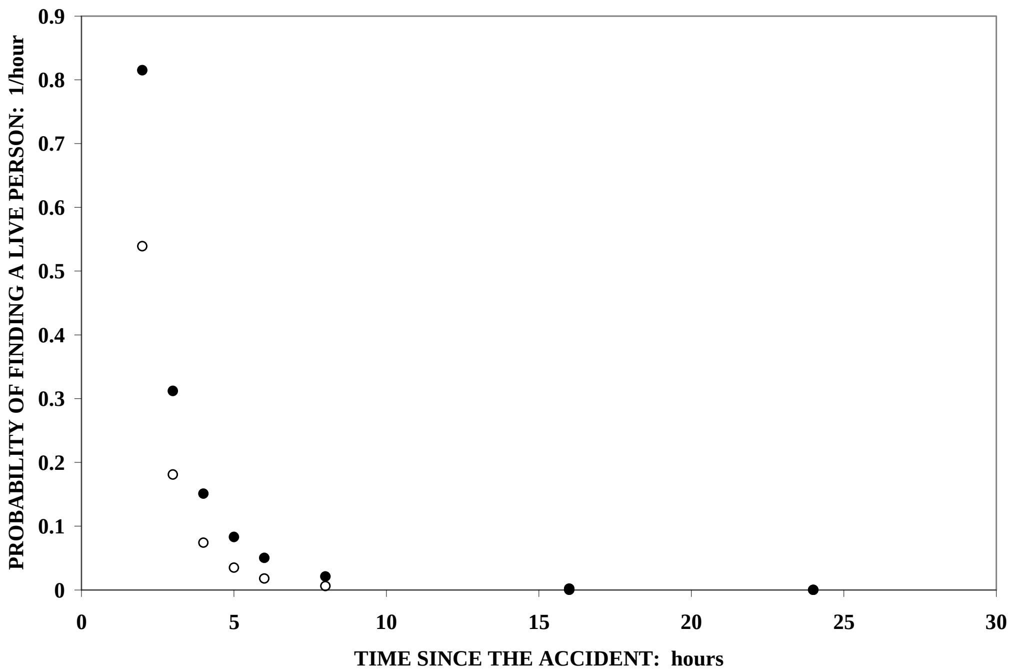

Figure B-6. Probability ($P_f\, P_s$) per unit search time of locating a person alive in the water t hours after the accident.

The analysis presented above is only approximate and probably has little practical value. However, it does illustrate the combined effect of finding the victim and the victim's ability to survive until rescued. Results illustrate clearly the value of rapid response and the futility of a prolonged search regardless of the expected survival time. Assuming that P_s(t) decreases exponentially with time in the water is probably an extreme assumption; the other limiting assumption is the $P_s = 1$ for $t < t_{es}$ and $P_s = 0$ for $t_{es} < t$. When the second assumption is made, the probability per hour of search time of locating a person alive in the water t hours after the accident is represented by the curve in Figure B-4 for $t < t_{es}$; for $t_{es} < t$, the probability is zero. Hence, a realistic probability lies between the curve represented in Figure B-4 (truncated for $t_{es}<t$) and a curve similar to those represented in Figure B-4 for expected survival times of 10 and 20 hours. The shape of the P_s(t) relationship is important for short expected survival times and becomes less important as t_{es} increases. While that conclusion is generally valid, application to a particular case depends on P_l(t). It would probably be worthwhile to have someone from the Coast Guard discuss their procedure for computing P_l(t) and the characteristics of the function at a future meeting.

A final comment may be in order. It is essential that prediction of survival time be made for a specific set of conditions. Presumably, that will happen in the field, but the necessity for specificity did not characterize discussions during the workshop. For example, there were several occasions when the subject changed abruptly from survival during immersion to survival in a life raft, or even to survival on land. Those are quite different conditions with different expected outcomes, and it is important to differentiate between them.

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Workshop Minutes: Excerpt from a Book Chapter written by Dr. Eugene Wissler

Evolution of Human Thermal Models

Before we delve into the details of model formulation, it is worthwhile to review briefly the history of human thermal models. Two of the earliest models are still in use in modified form by those whose principal concern is thermal comfort under moderately stressful conditions. The evolution of human thermal models outlined in this section reflects the author's prejudices, and others might construct a rather different version.

Probably the first model was developed by A. C. Burton in 1934 [5]. His very simple model represented the human body as a single homogeneous cylinder with uniform metabolic heat generation. It suggested that the steady-state temperature profile is parabolic in agreement with the experimental observations of Bazett and McGlone [6]. Subsequently, Burton and Bazett [7] used the transient solution of the heat conduction equation for the same system to interpret data obtained with their bath calorimeter.

Since the results of experimental studies are nearly always reported as central and mean skin temperatures, it followed quite naturally that a two-node model would be developed. Machle and Hatch [8] described a "core and shell model" in their extensive 1947 review paper summarizing the results of research conducted during World War II at the Armored Medical Research Laboratory in Fort Knox, KY and at the Pierce Laboratory at Yale University. Application of that model was not discussed and it was probably not very useful, because it neglected heat transfer between core and shell, assuming instead that core and shell temperatures were linearly related.

A significant milepost in the development of human thermal models occurred in 1948 with the publication of Pennes' classic paper [9] on the effect of blood flow on tissue temperature. Pennes advanced the notion that heat transfer between blood in small vessels and adjacent tissue is proportional to the product of the perfusion rate and the difference between blood and tissue temperatures. Although computed temperature profiles in the forearm had a slightly different shape from profiles measured by drawing a fine thermocouple through the forearm, the difference was eventually attributed to the way data for arms of different size were analyzed [10]. Most current detailed models employ the Pennes model (often referred to as the bioheat equation) to describe heat transfer in perfused tissue. Implicit in the Pennes model is the assumption that no heat transfer occurs between blood in small arteries and veins connected to capillaries and surrounding tissue. That assumption has been criticized and analyzed in considerable detail (for a summary of early work, see Charney [11]), with the resulting conclusion that Pennes' original model probably overestimates the rate of heat transfer between blood and tissue. Multiplication of the Pennes expression by a factor that depends on the perfusion rate provides a more accurate result [12, 13, 14].

Wissler [15] applied concepts developed in Pennes' paper to develop the first steady-state, multi-element, human thermal model. His model consisted of six homogeneous cylindrical elements representing the head, trunk, two arms, and two legs, which were connected by circulating blood. The thermal energy balance for blood made allowance for the effect of countercurrent heat transfer between arterial and venous blood. When reasonable values were assigned to metabolic and perfusion rates in the six elements and allowance was made for respiratory heat loss, acceptable agreement between computed and measured temperatures was obtained. That model did not consider the effect of thermal state on blood flow, sweat secretion, or shivering.

Information gained from studies conducted at the Pierce Laboratory during the next five years contributed greatly to our understanding of human thermoregulation. Transient changes in central (usually rectal) and mean skin temperatures were recorded during exposure of seated, lightly clad, male subjects to air temperatures ranging from 13 °C to 48 °C. Rates of metabolic heat generation and sweat secretion were determined by partitional calorimetry. The resulting data are still invaluable for testing human thermal models.

In 1966 Stolwijk and Hardy [4] significantly advanced the art of human thermal modeling with their publication of a theoretical study in which the concepts of feedback control were applied to human thermoregulation. Although those concepts were not original with Stolwijk and Hardy, the thoroughness of their analysis enhanced the validity of human thermal modeling.

The 1966 Stolwijk and Hardy model consisted of three cylindrical elements representing the head, trunk, and extremities. That model was implemented on an analog computer, which undoubtedly limited the number of elements and amount of detail it could contain. A total of seven regions represented the head core (brain), trunk muscle, trunk core (viscera), extremity core, and a 2 mm thick layer of skin on each element. The radius and length of each cylinder were defined so that it had a mass and surface area appropriate to the anatomical region represented. Heat transfer by conduction occurred between adjacent regions in proportion to the difference in regional temperatures. Blood contained in a central pool exchanged heat with tissue located in each region. The principal contribution of that model was that it incorporated control functions for skin blood flow, sweating, and shivering into a physically reasonable model. Subsequent models have all employed the approach introduced in that paper.

Two notable models evolved from the 1966 Stolwijk and Hardy model. In 1970 Stolwijk [3] developed a six-element model that ran on an early digital computer. Each element was subdivided into four regions representing a central core surrounded by muscle, subcutaneous fat, and skin. The regions were perfused with blood drawn from a central pool. Heat transfer by conduction between adjacent regions occurred at a rate proportional to the temperature difference between them. Using physiological control functions for skin blood flow, sweating, and shivering based on the best available information, Stolwijk and Hardy significantly advanced the art of human thermal modeling. Their model was used in the design and operation of the Portable Life Support System for the Apollo missions, and it is still employed in several thermal comfort models. For example, the Berkeley Multinode Comfort Model [16] is based on the 25-node Stolwijk model, although it has been augmented in many ways.

Also in 1970, Gagge [2] developed a simple two-node model for the purpose of evaluating thermal stress imposed by a given environment. His objective was to develop an effective temperature scale that would allow engineers and environmental scientists to compare thermal environments on the basis of energy exchange. That simple model still finds application, although one must question the virtue of extreme simplicity when powerful computational facilities are readily available. Moreover, a recent study by Jay, et al. [17] reaffirmed that using core and mean skin temperatures to estimate the internal energy content of the human body is quite inaccurate [18]. However, for the record, we mention an example of that approach provided by Bruse's Individual Thermal Comfort Model [19] which is based on the two-node Gagge model.

The summary presented above is by no means complete. Other variants of human thermal models evolved from the Stolwijk and Hardy model, but their existence was often transient, and limitations of space and time preclude including them in this document.

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Workshop Minutes: List of Attendees

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APPENDIX C. YORKTOWN GUIDANCE PRODUCT AND REQUIREMENTS REFINEMENTS WORKSHOP MINUTES

Workshop Minutes (Revision 1)

Enterprise Solutions Division
23 Clara Drive, Suite 206
Mystic, CT 06355-1959
Contract No. HSCG32-05-D-R00010
Task Order HSCG32-08-J-100043
Control No. SAIC:001:TM:0002:043:002/-(U)

6 October 2008

Subject: Survivability of Mariners: Guidance tool development workshop minutes
Date Held: 18 September 2008
Location: Yorktown, VA
Attendees: See Enclosure (1)

Introduction

Introductions were made by Chris Turner.

Presentation of PowerPoint (Dr. Parker)

- Comments from attendees:
    - Line between cold water and warm water? Where do we draw distinction?
        - Chris: We are not differentiating, just looking at what happens to this person.
    - Celsius v. Fahrenheit? Layman does not use ºC, need to make sure model converts to ºF automatically.
    - Difference between huddled person and someone with legs/arms out in conserving core temperature?
        - Chris: No real difference that we can tell; no idea if experiments have been done to back up.
        - Navy Seals suggested as willing test subjects.
    - Question about diving reflex: is it taken into account?
        - No, not taken into account because we are looking at death due to hypothermia. At all but the very coldest temperatures, hypothermia occurs after longer time periods.
    - No one uses CESM help function; no one even knew there was a user manual.
    - CESM is used as a “black box”: users open it up, enter numbers, and don’t really think about processes behind it.
        - Students get ½ hour and/or one PP slide in SAR school training; the participants stated that some SAR School sessions don’t even include a discussion of CESM.
- On proposed requirements:
    - Would like a slider function that shows visual summary of survivability and that can slide out to view end survival time.
    - No one really knows why or when to use the tool; not taught.
    - Sea state requirement: data may be hard to come by (may not be a data buoy in the area); but automatic ingestion would be great; can’t leave it up to each controller to put in data because each one would enter subjective information.
        - Chris: want sea surface temperature, sea state, and air temperature information included in EDS so information retrieval would be automatic from there.
    - Want output to be easy to pull into MISLE from SAROPS.
        - Users like MISLE Export Function idea a lot.
    - How do we account for time spent in the water?
        - Example of merchant ship with man overboard: missing 8 hours, no one knows when he went into the water exactly.
        - Can model account for this? Probability of success must consider the breadth of the search area and the survival time of the victim.
        - Chris explained that when incorporated into SAROPS, the model would provide survival attributes for particles released during a trip scenario. Particles released early in the trip scenario could expire. The search planner in SAROPS would optimize the search on particles still alive, to optimize the Probability of Success for the search on victim survival.
    - On some PIW cases, resource usage is based on CESM data; controllers make decisions on what craft to use, which craft can be allocated elsewhere.

  - Model needs to have high enough confidence to support decision to suspend around the time indicated by the model to prevent waste of assets.
  - The group was very interested in a product that would reduce over-utilization of CG search platforms.
- For clothing options: do not want pop-up visuals of clothing. Just want a pulldown menu. Best-case scenario clothing might be all that is really needed.
- Some safety factor (time) is built in if CESM run begins after the incident, and not after the actual start of immersion. If ST expires at night, the effort will continue to include a first-light search.
- Would be helpful to present outputs of multiple scenarios on one screen.
- Default scenario: if body make-up/victim age, etc. are unknown:
  - Tool would run a stochastic model.
- NOK notification: this graphic output may be useful if it could show NOK that search was scientifically valid; may not use actual model that command center is using, but something similar ("watered down" output) would give them concrete data/closure; right now don't give them any scientific data, such as historical case summaries.
- Like GUI graph: much better than what they have now (do not like simple numbers; want graphic).
- Would not necessarily want to see historical output box, especially maximum time outliers. NOK would probably misinterpret or misunderstand this information.
- Don't really need model until thinking of suspension.
  - One case did run it immediately because local agencies already were searching prior to USCG notification.
- Everyone dislikes CITRIX; have many problems with it.
- In policy, need to make it clear that this is head-above-water immersion; there is no clear (observed submersion) drowning policy right now.
  - How does model handle changing environments: from sea to land or vice versa? This scenario would be very complicated because the time of the change would not be known. This scenario cannot be addressed in this version of the guidance.
- Graphic: controllers would get questions about period of degrading functionality; would like to see what is going on with the person (physiologically) inside that box, and as they approach threshold of box (are they unconscious, unable to swim, heart failure?).
  - List of degrading body functions in hierarchy. Points on line within blue box. This keyed on the discussion by Dr. Parker of physiological symptoms associated with the range of core temperatures.
- Interpreting graph accurately for decision-makers is important; need to give chain-of-command interpretation of what is happening. So long as controller understands what graphic/tool is ACTUALLY DOING, they are going to be able to use it.
- Range of curves in one screen to account for several scenarios.
  - Like 3 different lines: so have visual bracket to see which scenario they want to aim for.
  - This request was prompted by the controllers' need to have information available on the best case/worst case scenarios for the SAR mission controller.
  - The scenario of the sinking commercial fishing vessel was brought up as the example. The crew could be in their skivvies, in working clothes, or be wearing survival suits. They could also be in a raft or in the water.

  - Don't want core temperature curve because not enough data behind core temperature at death.
  - One-page synopsis of how to use/interpret this model for decision makers so they understand finer points of tool.
  - People who are just plugging in the numbers really do NOT need to know finer points; they don't need to understand rationale like the decision maker does.
  - % immersion needs to be shown in output of GUI.
    - Life raft, partial flotation vs. complete immersion, land.
  - Is NOK line representative of Addendum? Addendum states that notification should be done 24 hours prior to suspension.
  - Want hyperlink to clean up "NOK version" of graph that they can show.
  - Ability to extract parts of this and pull it into another product? Text format of multiple runs in one file?
  - Users would like to see better policy on the credibility of the tool for the decision maker; similar to policy used now to decide when medevac will be used. Users tend to only believe model outputs when they are backed by an expert (e.g., flight surgeons evaluate risk/reward for medevacs).
    - i.e., only recommend medevac when doing so will affect survival of victim.
  - Success will be measured by user confidence in the new tool.
  - Grey bar (survival highly unlikely) needs to give guidance for when suspension is likely; give one number that applies to all districts and commands that says you don't need to search beyond this point.
    - Visual should help with decision.
    - Make grey bar = "ACTSUS RECOMMENDED."
  - By defining upper limit, based on considerable number of cases, controllers can see relationships and have better confidence in data points given.
    - Low confidence in accuracy of CESM survival time numbers has lead to longer than necessary searches in the past.
  - Just number with no understanding won't be much better for decision making.
  - Need PowerPoint for command/decision makers during their training.
  - Show periods of day/night on the graph.
  - Don't need historical data for ACTSUS; get rid of yellow box on strawman GUI.
  - Don't need unit case number.
  - Export → MISLE/SAROPS/REPORT/EXCEL.
  - Will tool be tested by users before being sent out? First users most likely will be pilot units?
  - Like idea of pop-up box with explanation of difference in time and patient condition readily available.
- Art Allen dropped in:
  - Office of SAR would like to get this implemented into SAROPS by version 1.2, maybe 2.0 if needed extra time.
  - Would then get put into particles themselves in SAROPS so can optimize detection of live object.
  - Right now, PIW in SAROPS has infinite lifetime, but would like to use tool to assign probability of survival factor so can show decay of particles over time; better assignment of search assets.
  - Proposed new policy will not require searching all area to achieve 0.1 POD (target can drift out of area during extended search).

Workshop Minutes: List of Attendees

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APPENDIX D. CG FORM 5214

EMERGENCY MEDICAL TREATMENT REPORT

VICTIM IDENTIFICATION

1. Name ____________________
2. Sex (check one) male ____ female ____
3. Estimated age yrs ____ mos ____

RESCUER INFORMATION

10. Name: ____________________ 11. Level:
12. Unit: ____________________
13. OPFAC #: ____________________
14. Rescue Vehicle: ____________________
15. Receiving Unit: ____________________
16. Time Patient Transferred: ____________________

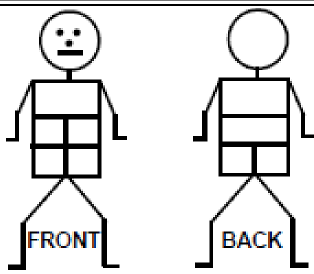
DESCRIPTION OF INCIDENT

4. Date: ____________
6. Time on scene: ____________
7. Time of incident: ____________
8. Location: ____________

5. Type of incident:
a) marine ____
b) aviation ____
c) industrial ____
d) auto ____
e) domestic ____
f) other ____

NATURE OF EMERGENCY / MECHANISM OF INJURY

OBSERVATION OF VICTIM



H - hemmorage
L - laceration
S - soft tissue injury
F - fracture
B - burns

TREATMENT (circle as needed)
1 - dressing
2 - tx splint
3 - splint
4 - c/collar
5 - back board
6 - tourniquet
7 - CPR
8 - airway
9 - oxygen
10 - MAST
11 - Miller B/B
O2 Liters ____

MEDICATIONS:

ALLERGIES:

MEDICAL HISTORY / COMMENTS / ETC.
(include additional vitals, oxygen, fluids, etc.)

SKIN
(Circle appropriate number or numbers)
1 - normal
2 - pale/ashen
3 - flushed
4 - cyanotic
5 - dry
6 - moist
7 - cold
8 - warm
9 - hot

	OBSERVED / TIME				
VITAL SIGNS					
LEVEL OF CONSCIOUS	Alert				
	Responds to Verbal				
	Responds to Pain				
	Uncon / Unresponsive				
PUPILS	Perl				
	Unequal				
	Nonreactive				
	Dilated				
	Pinpoint				
PULSE	Rate (Numeric)				
	Strong				
	Weak				
BREATHING	Rate (Numeric)				
	Regular				
	Shallow				
	Labored				
BLOOD PRESSURE	Blood Pressure				
TEMP	Temperature (circle) ORAL RECTAL				
MAST	MAST BP				
	COMPARTMENT		R	L	ABD

TIME	MEDICATIONS ADMINISTERED	DOSAGE

TRIAGE INFORMATION (CIRCLE ONE) PRIORITY I PRIORITY II PRIORITY III

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Figure D-1. CG form 5214.

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